Strategy for Development of Mineral Based Industries in Odisha



Edited by

B. Bhoi, S.K. Mishra & S.Basu

CSIR-IMMT, Bhubaneswar, Odisha

In association with

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Former Deputy General Manager & Head (R&D)

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March - 2018



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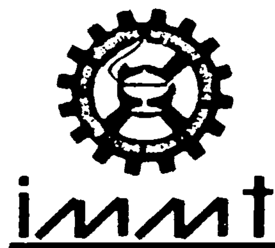
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March - 2018

FOREWORD

I have a great pleasure in writing a foreword for the compendium entitled " **Strategy for Development of Mineral based Industries in Odisha**" containing relevant publications on the subject. The information duly compiled and edited by the authors is for internal circulation and will be of great benefits to the researchers, engineers, technocrats, planners, mine owners and executives involved in the development of mineral based industries in Odisha.

Prof. Suddhasatwa Basu
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ACKNOWLEDGEMENT

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The authors also express their sincere thanks to scientists and staff members of CSIR-Institute of Minerals and Materials Technology, Bhubaneswar for their support, suggestion and discussions while preparing this book.

The authors are also grateful to the Director,CSIR-Institute of Minerals and Materials Technology, Bhubaneswar for his kind permission to publish this book.

B.Bhoi
S.K.Mishra
S.Basu
C.R.Mishra and
H.P.Mishra

PREFACE

Strategy for Development of Mineral Based Industries in Odisha is about providing engineering leadership, bringing about technological change and ultimately contributing to the economic development of the state. This is the brain child of Dr. H.P. Mishra former Chairman, IPICOL, Bhubaneswar, Odisha. Now Dr. Mishra is at the flag-end of his career's journey after retirement but still his zeal, interest and enthusiasm towards the profession know no boundaries. Dr. Mishra's career with FCI, IDC, IDCOL, IPICOL and M/s M.N. Dastur is a testimony to his exemplary leadership and commitment to industrialization of Odisha.

For last few decades after 1970 our state has promoted some vital mineral based industries specially in iron and steel, ferrous-alloys, alumina & aluminium industries. These industries are providing infrastructure for promoting industrialization, but the real industrialization will be measured how much of these basic metal is getting converted to technological products through mega, medium and small scale industries.

In our present industrialization programme, for converting our mineral resources to basic metal like iron & steel, ferro alloy and alumina & aluminium etc. besides the mineral, water, power, human resource are used.

The profit margin available in these if computed is marginal. However, the availability of these basic materials is essential to utilize our technological knowledge and human skill for high value technological product required nationally and internationally for various industries e.g. automobile, electronic and consumable products.

For creating these, we have to plan out different projects in contrast to the existing one. In our steel corridor which encompasses basic metal producing units, industrial projects must be developed facilitating installation of medium and small scale industries besides mega one in which the basic metal can be processed for technological products of high value utilizing our infrastructure and technical manpower.

This book provides a compilation of article that will serve as a useful reference to industries, institutions, students, libraries and to all other related and interested in the development of mineral based industries in Odisha.

Dr. S. C. JAMIR
Governor, Odisha



RAJ BHAVAN
BHUBANESWAR-751008



June 17, 2016

MESSAGE

I am glad to know that Dr. Ing. H.P. Mishra, ex-Chairman, IPICOL is bringing out a book titled 'Strategy for development of mineral base Industry' shortly.

Odisha is a state rich in minerals. The state's economic prosperity depends to a great extent on proper and effective utilisation of natural resources, particularly mineral resources. Minerals are vital raw materials for many basic industries and are major inputs in industrial development. This sector has huge potential for attracting large investments to create employment and raise resources. No wonder that the state is yet to attain its full potential when it comes to industrialisation. It is important to adopt right kind of strategy for development of mineral based industry. The endeavour of Dr. Misra who has a long experience and knowledge in this field in bringing out such a useful book is indeed laudable.

I wish the endeavour and publication all success.

(S.C. Jamir)

C. J. Venugopal, *IAS*
Principal Secretary to
the Governor, Odisha



RAJ BHAVAN
Bhubaneswar-751008



June 09, 2016

MESSAGE

I am happy to know that Dr. Ing. H.P. Mishra, ex-Chairman, IPICOL is bringing out a book titled 'Strategy for development of mineral based Industry'.

Odisha has an abundance of good quality mineral deposits. The rich potential of minerals is always seen as a resource to achieve economic prosperity. The potential for growth in mining and mineral based industries in the state is immense. These industries constitute the bedrock of industrial development as they provide the basic raw materials for most of the industries. The state government has taken a number of positive steps to promote industrial development in Odisha formulating an investor and business friendly policy. The effort taken by Dr. Mishra to bring out a book from his long experience and outlook is surely commendable. I am sure the book will be enlightening and informative as well.

I wish the publication all success.

(C.J. Venugopal)

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CHAPATER 1

Technology, Economics and Industrialization

Industrialisation of Odisha and the Key Factor Leading to Economic Development



H. P. Mishra



B.Bhoi



P. R. Behera

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This article emphasises on the necessity of creating medium and small scale industries manufacturing technological products in automobiles, electronic, various construction profiles and household appliances. This will provide value addition to India's basic metals like iron & steel, Ferro-alloys, sponge, alumina, aluminium, etc. and further create job opportunities, especially for the nation's skilled personnel. This is the key to India's economic growth as in case of China.

Introduction

Currently, the industrialisation of Odisha is passing through a critical stage. To address the situation, this matter needs to be discussed thoroughly. In the past, the Government had taken up a number of mega projects such as, the Hydro Project at Hirakud, Rourkela Steel Plant, Thermal Power Plant at Talcher, Fertiliser Plant at Talcher, Rare earth Plant at Gopalpur, etc. Some of the other major plants that came up at the end of the 20th century are, Alumina and Aluminium Plants under NALCO, Sponge Iron Plants or DRI units at Rourkela and Keonjhar, Ferro-alloys Plants in Koraput and various types of Steel Plants at Kalinganagar, etc. By making a proper utilisation of mineral resources, electricty, water, etc. these plants are able to produce many useful basic metals and related materials like steel, sponge iron, aluminium, Ferro-alloys, etc.

To facilitate further growth of industries, the importance of production of these materials cannot be neglected. Based on this, many household items and other application oriented items are being produced. To name some of the essential sectors like automobiles, electronic gadgets, infrastructure and construction, capital goods, railways, defence, white goods, etc. all are being produced from these basic metals.

If the application of these useful metals does not bloom in the right manner, India's, and Odisha's, in particular, actual progress in the field of industrilisation will be hindered. In comparison to the amount of minerals, electricity, water, and man power employed to achieve industrial growth, the profitablity is marginal and it creates a diminishing job opportunity amidst the people of the state. As a matter of fact, the countries importing these materials from the nation are the actual profit-makers in this situation. Those countries utilise these metals in the form of raw materials for their small scale industries.

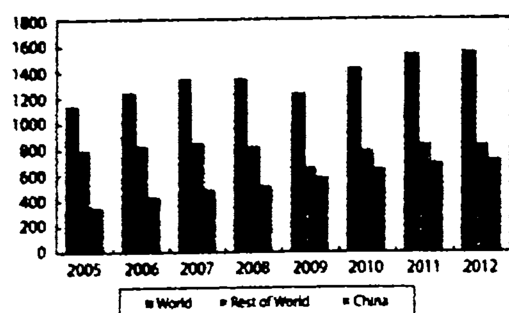
Many foreign companies have shown their interests to produce application oriented materials in their countries using the raw materials of Odisha. Now, it is high time to pressurise the production firms of all these metals (raw materials) to expand their capacity and efforts to manufacture the end products mentioned above. As a consequence, the state's raw materials will be utilised for the best interest of its people, thereby producing many value added end products to meet their daily needs as well as creating job opportunities for the common people. Following this trend, industrialisation of Odisha can actually be taken to a new height.

China will be the fitting example in this regard, which has carved a niche for itself in utilising iron & steel, aluminium, etc. to produce various useful application based materials. As a result, it is counted among the most prosperous nations in the world at present. The time is now ripe to compel industrialists to follow this path. They should be encouraged in the right direction to establish industries for the benefit of India and her people. The fact that mineral resources will face depletion sooner or later should be equally reckoned. Hence, it is required to be very watchful about their use, or the future generation might face the consequence of scarcity and non-availability of the prime raw materials. It may be noted that the mineral resources of India are non-renewable and must be used and preserved for the future generation.

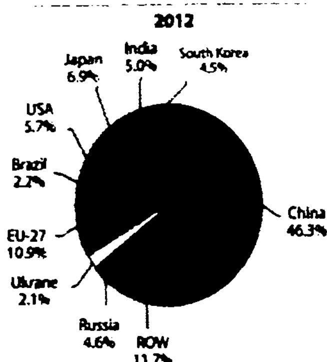
World's Crude Steel Production

The global output of crude steel production for the 59 countries reporting to the World Steel Association (world steel) was 1548 MT for the year 2012, up by 1.2% as compared

to 2011. Figure 1 represents a comparative scenario of annual steel production in the world from 2005 to 2012, with indices as 'world', 'rest of the world' and 'China'. Share of world's



World Crude Steel Production in MT



Share in % (2012)

Fig 1: Comparative scenario of annual steel production in the world from 2005 to 2012 and share in percentage of different countries

steel production during 2011 and 2012 has also been represented in figure 1. It is observed that China is a major player in steel production in the world contributing around 46%, followed by Japan, U.S., India and others.

Crude Steel Production in India

The top 10 steel producing countries in 2012 have been shown in table 1. China, the leading steel producing country in the world, produced 716.5 MT of steel which was 3.1% more than the production in 2011. India, following Japan and the United States, was in the 4th rank producing 76.7 Mt in 2012, which was 4.3% more than its production in 2011. The

Rank	Country	2012 (Mt)	2011(Mt)	2012/2011(%)
1	China	716.5	694.8	3.1
2	Japan	107.2	107.6	-0.3
3	United States	88.6	86.4	2.5
4	India	76.7	73.6	4.3
5	Russia	70.6	68.9	2.5
6	South Korea	69.3	68.5	1.2
7	Germany	42.7	44.3	-3.7
8	Turkey	35.9	34.1	5.2
9	Brazil	34.7	35.2	-1.5
10	Ukraine	32.9	35.3	-6.9

Steel Authority is estimating to increase the production of steel up to 300 MT in 2025. The trend of steel production is continuously increasing every year as the demand of steel in developing countries is going up. The projected production trend of crude steel till financial year 2017 in India has been shown in figure 2. The leading steelmakers in India and their production share have also been shown in figure 3.

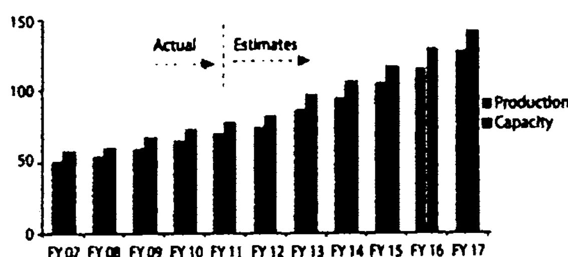


Fig 2: India's crude steel production trend and projection - FY 2007 to FY 2017

Crude Steel Production Share in MT (2007-11)

Producer	FY07	FY08	FY09	FY10	FY11(P)
SAIL	13.51	13.98	13.41	13.51	13.76
RINL	3.50	3.13	2.96	3.21	3.24
Tata Steel	5.17	5.01	5.85	6.56	6.86
JSW	2.64	3.15	3.22	5.26	5.85
ISPAT	2.76	2.83	2.20	2.69	2.38
ESSAR	3.01	3.54	3.34	3.47	3.37
JSPL	-	-	1.46	1.96	2.27
Others-1	4.84	5.78	8.15	9.36	9.79
Others-2	15.39	16.93	18.05	19.82	22.07
Total	50.82	53.86	58.44	65.84	69.58

Others-1: Includes production from EAF Units/COREX-BOF
Others-2: Includes production from induction furnace

Share in % (2011)

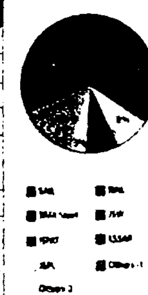


Fig. 3: Leading steel producers in India and their production share: FY 2007 to FY 2011

Indian steel industry: Imports (In million tonnes)					
Category	2007-08	2008-09	2009-10	2010-11	2011-12*
Total Finished Steel (alloy + non alloy)	7.03	5.84	7.38	6.66	6.83

Source: Joint Plant Committee; *provisional

The per capita consumption of steel in India is very low as compared to China. It is approximately 10 times less than that of China.

Steel Imports

Iron & steel are freely importable as per the extant policy. The import of total finished steel (alloy + non alloy) in the last five years has been given above in table 3. The previous trends and future estimates (nearly 4 million tonnes in the upcoming financial year 2016-17), pertinent to steel imports, have also been indicated in figure 4.

Steel Exports

As per the Indian law policy, iron & steel are freely

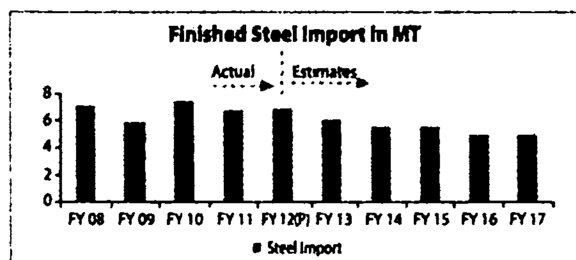


Fig.4: Steel imports in India: past trends and future estimates: 2007-08 to 2017

Indian steel Industry: Exports (in million tonnes)					
Category	2007-08	2008-09	2009-10	2010-11	2011-12*
Total Finished Steel (alloy + non alloy)	5.08	4.44	3.25	3.64	4.04

Source: Joint Plant Committee; *provisional

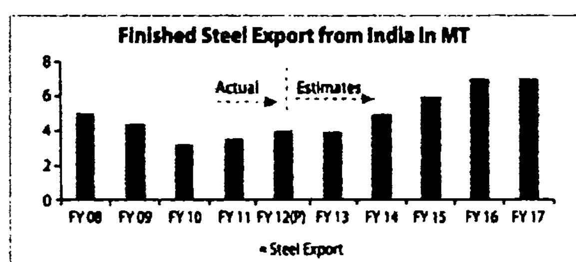


Fig 5: Steel exports from India past trends and future estimates: 2007-08 to 2017

exportable. The export of total finished steel (alloy + non alloy) during the last five years has been given in table 4. The steel export trend has also been demonstrated in the form of past trends and future estimates (6 million tonnes in upcoming financial year 2016-17) in figure 5.

The Production of Ferro-alloys in India

As per Indian Ferro-alloys Producers Association (IFAPA), at present, the total installed capacity of bulk Ferro-alloys industry in India is 5.10 million tonnes per annum and noble Ferro-alloys is 50,000 tonnes per annum. The industry is reported to be working at about 60-65% capacity utilisation. The capacity of Ferro-alloys in India is given in table 5. The production of various Ferro-alloys, as reported by IFAPA, is given in figures 6 to 9. Figure 6 shows the production of high carbon Ferro-alloys during 2008-09 to 2011-12. The production of low carbon Ferro-alloys and noble Ferro-alloys has been shown in figures 7, 8 & 9 respectively.

Ferro-alloy	Installed Capacity
(a) Bulk Ferro-alloys	
(i) Manganese alloys	3160000
(ii) Chrome alloys	1690000
(iii) Ferro-silicon	250000
(b) Nobel Ferro-alloys	50000
Total	5150000

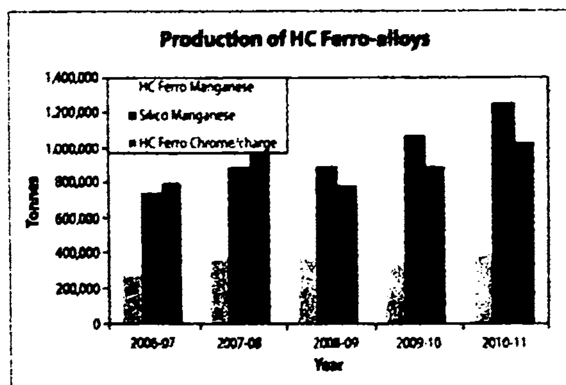


Fig.6: Production of high carbon Ferro-alloys during 2008-09 to 2011-12 (Tonnes)

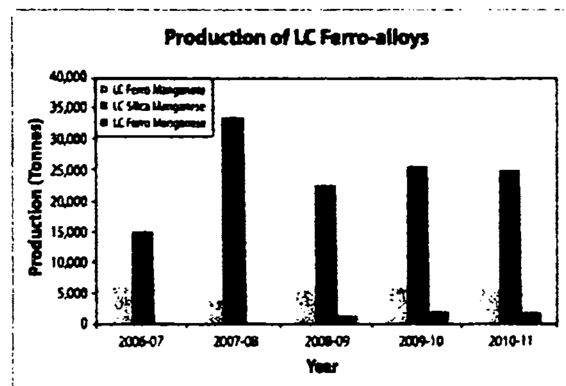


Fig.7: Production of low carbon Ferro-alloys during 2008-09 to 2011-12 (Tonnes)

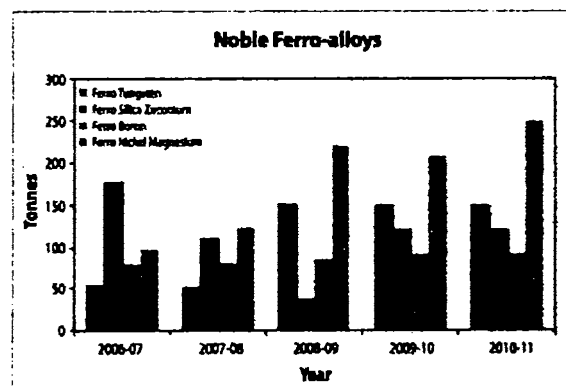


Fig.8 Production of Noble Ferro-alloys during 2008-09 to 2011-12 (Tonnes)

Production of Aluminium in India

India, with its abundant supply of quality bauxite and low cost labour has established itself as a low cost producer of primary aluminium. Global primary aluminium production in 2012 was 45.2 million tonnes, with China accounting for an astounding 19.8 million tonnes or 44%. However, in India, the production of primary aluminium has stagnated around the 1.6 to 1.7 million tonne mark for the last three years which has been indicated in figure 10. The three primary aluminium producers, viz. Hindalco, Vedanta and Nalco have

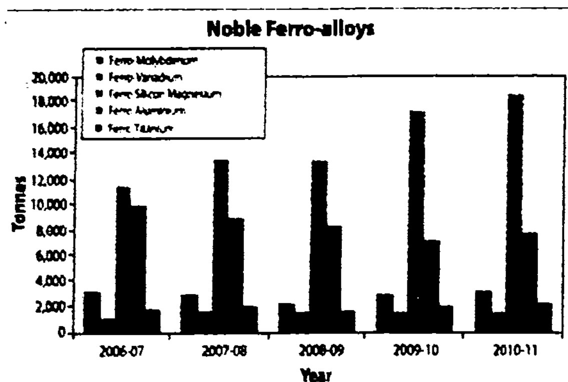


Fig. 9: Production of Noble Ferro-alloys during 2008-09 to 2011-12 (Tonnes)

expansion plans as well as Greenfield projects that are expected to take the production to 2.5 to 3.0 million tonnes in the foreseeable future.

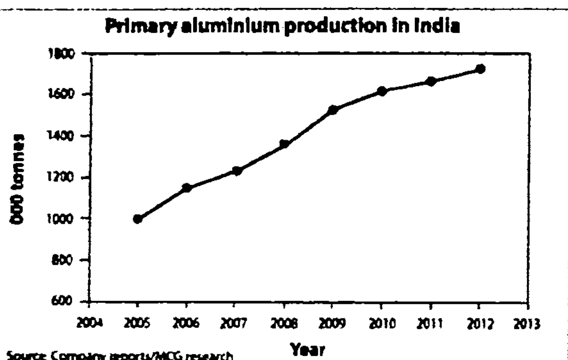


Fig.10 Aluminium production trend in India

Import and export of primary aluminium in India have increased over the years and kept pace with each other, making the sector increasingly globalised. The trends for both imports and exports in the last five years have been illustrated in table 6.

India: Primary aluminium import & export ('000 tonnes)					
	2008	2009	2010	2011	2012
Import	184	241	228	243	308
Export	234	285	266	270	300

Source: Ministry of Commerce and Industry

Recycled (secondary) aluminium production has surged in India, driven strongly by the demand for castings from the automotive sector. As the generation of aluminium scrap is limited within the country, scrap imports have grown significantly. However, the recent imposition of 2.5% customs duty on aluminium scrap import will act as a damper and some slow-down in the recycled aluminium sector can be foreseen.

Production of DRI in India

India has become the leading producer of DRI over the past decade due to production, in a large number, of small coal-based rotary kilns; however, the need for better quality DRI is driving shaft furnace alternatives such as, MXCOL® and Corex/Midrex. With smaller amounts of natural gas anticipated for industry use, coal-based technology options are currently being pursued by a few India steelmakers. Jindal Steel and Power Ltd. is currently building a 1.8 MXCOL plant in Angul, Odisha in India to produce syngas for use in a Midrex DRI shaft furnace. Also, a 1.2 Corex plant will supply a Midrex plant with gas at Vijayanagar, Toranagallu, and Karnataka state in India by Jindal South West (JSW) Projects Ltd.

India produced 22 Mt DRI in 2011, a drop of 1.45 Mt(7%) from 2010, but the country still remains the world's largest producer by a wide margin. As per the data provided by the World Steel Association, India remains the highest producer of DRI 2012 with 1550 thousand tonnes till October 2012 compared to other 13 countries in the world. The production figures have been cited in table 7.

Countries	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Canada	84	73	87	87	71	101	135	129	132	72
Mexico	554	472	553	455	486	499	551	558	475	490e
Trinidad and Tobago	155	125	116	172	117	147	173	181	195	141
Argentina	159	137	158	157	139	88	55	40	106	158
Peru	8	8	7	10	6	8	7	7	8	10e
Venezuela	262	281	229	273	298	320	287	239	251	260e
Egypt	283	241	274	268	271	233	256	250	258	258
Libya	52	106	140	125	108	64	58	48	79	37
South Africa	136e	112e	130e	117e	136e	130e	130e	130e	126e	130e
Iran	868	992	1,137	1,234	1,304	1,314	1,314	1,278	1,274	1,223
Qatar	211	195	228	220	224	145	218	208	147	182
Saudi Arabia	424	436	400	437	440	379	406	460	463	496
United Arab Emirates	269	246	207	183	304	301	290	284	280	281
India	1,645	1,609	1,619	1,514	1,521	1,516	1,524	1,518	1,497	1,550e
Total 14 countries(d)	**5,110**	**5,034**	**5,283**	**5,252**	**5,425**	**5,244**	**5,404**	**5,331**	**5,291**	**5,287**

Future Outlook

The call of the hour is to encourage other user industries in India to come forward and take the responsibility of production of day to day household products, using the country's basic metals. This will not only bridge the gap between export and import of basic metals like iron & steel, aluminium,etc. but also make the nation self-dependent. The manufacturing industries must realise this fact that it is the nation's own resource which is being smartly purchased by other countries and India ends up buying the end-products made from the same resource at higher prices from them. To address this situation, steps to create jobs for India's skilled personnel should be taken immediately. It may be realised along with the expansion of the country's engineering institutions that, India has got the largest number of the skilled personnel coming out from these institutions and their placement is undergoing a deep national crisis. Creation of

the medium and small industries is the basic need of the hour to address this problem. Further, value added basic metal end products will enrich India's national wealth, and after use for some years, these can be recycled using the latest technology for producing mineral resources. It is high time to generate national consciousness on this matter, at the Govrnment and public levels.

Conclusion

For the past two decades, India has seen a tremendous rise in production of the basic metals. But surprisingly, this has helped in improving the industrialisation of other countries. The way the nation has adopted to employ its work power and sincerity, it works in favour of other countries. Now, it is the right time to alter this approach, or poverty will invade the country for centuries. It is only the growth of manufacturing industries, based on India's public raw materials, that can take care of the development of the states and the entire country as well.

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• *Source: Iron and Steel Review, Vol. 57, No. 8, January 2014, pp 76-84.*

Green Technology Challenges in Chemical and Metallurgical Industries

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Paying heed to environmental issues is gaining immense importance for a sustainable planet. Pollution of air, water and land, for the most part, is caused by different industries. Chemical industries are one of the main sources for creating water, land and air pollution. It has been estimated that pollution caused by chemical industries accounts for about 8 to 10% out of the total pollution. Moreover, with an increase in population, the product requirement also boosts up parallelly in many folds and so, production from chemical as well as metallurgical industries cannot be trimmed down. Nevertheless, a technology can always be developed by which pollution from chemical and metallurgical industries can be reduced or eliminated up to a certain extent. In this paper, efforts have been made to decrease major sources of pollution to tune our environmental processes used in chemical and metallurgical industries.

Introduction

Today's world is faced with a host of serious environmental problems and industrial wastes are one of the top causes of pollution. Scientific research has also found out that industrial wastes are the main sources for creating different types of pollution such as, water, air and land pollution. Commercial or industrial wastes account for a significant portion of solid wastes. Much of it, however, is classified as non-hazardous such as, construction materials (wood, concrete, bricks, glass, etc.) and medical wastes (bandages, surgical gloves, surgical instruments, discarded needles, etc.). Hazardous waste, on the other hand, is any liquid, solid or sludge waste that contains properties that are potentially harmful for human health or the environment. Industries generate hazardous wastes from mining, petroleum refining, pesticide manufacturing and other chemical production. Households generate hazardous wastes as well, including paints and solvents, motor oil, fluorescent lights, aerosol cans, and ammunition.

This paper discusses about the major pollutions created in chemical and metallurgical industries and factors controlling them.

Major Causes of Pollution

Chemical Industry

The various ways through which chemical pollution is caused and their adverse effects have been discussed below:

From Industrial Wastes

When industrial wastes containing poisonous chemicals are dumped carelessly, they contaminate vegetation, surface water as well as ground water supply. Some of the industrial pollutants that have been put into our natural waters or buried in the ground on large scale are acids, bases, salts, metal solutions, oil greases, dyes, waste solvents, and poisonous elements such as, cyanides, mercury and variety of other chemicals.

Accidents in Chemical Factories

Sometimes chemical pollution is caused by the accidental release of some toxic chemicals in the factory. For example, an accident took place in the Union Carbide Plant at Bhopal in December 1984. In this incident, highly toxic Methyl Isocyanate (MIC) gas leaked from the plant resulting in the death of thousands of people and animals in the surrounding localities.

Excessive Use of Fertilizers

The excessive use of chemical fertilizers to boost production also leads to contamination of various water bodies. Contamination of water with fertilizers leads to much undesirable effects such as, eutrophication. This is due to the reason that phosphate and nitrate encourage the growth of algae, which deplete the water body of its oxygen content.

Use of Pesticides

Pesticides are chemicals which are toxic in nature and get progressively concentrated in the food chain. These chemicals can cause long-term damage to the health of human beings. Pesticides also enter our bodies directly if the food articles, to which these chemicals are sticking, are not thoroughly washed before consuming.

Leases of Gaseous Pollutants in Air

Many industries release large number of pollutants in the atmosphere. These pollutants are responsible for variety of

diseases. Persons exposed to carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2), hydrocarbons and particulate matter suffer from headache, dizziness, irritation of the eyes and nose, allergies, chest pain and many respiratory disorders.

Pollution Caused by Dust

Certain industries give rise to considerable amounts of dust. Workers exposed to various types of injurious dusts suffer from a number of ailments. Pneumoconiosis, for example, is caused by inhalation of coal dust. Workers in coal mines suffer from this disease. Again, Silicosis is caused by stone (silica) dust. Workers in stone quarries or those engaged in the cutting and grinding of stone are mostly seen to suffer from this disease. Asbestosis is another such disease caused by asbestos dust while Siderosis is caused by iron dust. The persons exposed to smoke and other gaseous pollutants are also more prone to lung disorders and infections.

Mining and Metallurgical Industry

The mining and metallurgical industries were known to be sources of toxic materials since ancient times. Processing of minerals and production of metals have increased greatly in recent years. As a result, the quantities of waste material and pollutants have also risen. The general problems in the mineral and metal industries are shown in Fig. 1. It clearly shows the main emissions and sources of pollution in the mineral processing industry. Different sources of mining and metallurgical pollutions are described in the following section.

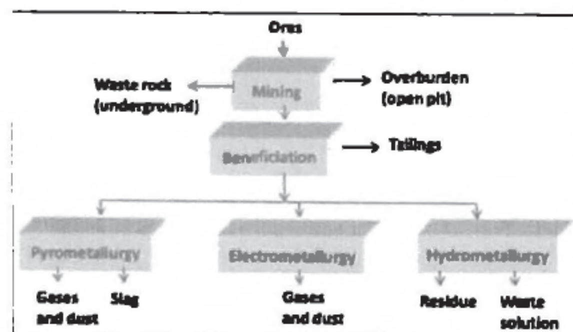


Fig. 1: Emissions and waste disposal problems in the mineral industry

Mining

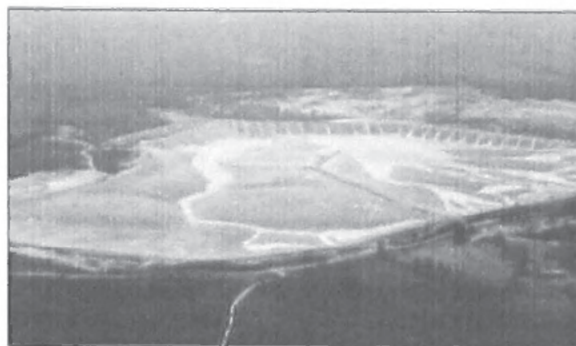
Pollution in mining is mainly due to the waste rock that is brought to the surface from underground and the overburden removed from open pits. As the solids accumulate, a dump covering many acres is formed (Fig. 2). Explosives used in mining produce nitrogen monoxide (NO) and nitrogen dioxide (NO_2) gases, usually denoted as NO_x, which contribute to the problem of acid rain. Mining radioactive ores is especially hazardous because of the liberation of radioactive gases during shattering the rocks. Excessive ventilation is necessary in underground mining. Mine water contains residual ammonium ion from the explosives used, which may be reduced by micro-organisms to ammonia (NH_3) that are toxic to aquatic animals.



Pic. 1: Waste rock accumulating from a mining operation

Mineral beneficiation

Ores supplied by the mines are usually beneficiated to remove, as much as possible, the undesired components known as gangue minerals. This operation is essential to decrease the cost of transportation and increase the value of the concentrate obtained. The minerals must first be liberated from the rock by crushing and grinding, and then subjected to a separation process making use of differences in a physical or a physico-chemical property. The waste from this operation is known as tailings.



Pic. 2: A view of a typical tailings pond

Extractive metallurgy

The major pollution problems in metallurgical plants arise in iron and steelmaking, aluminium industry, in the treatment of non-ferrous sulphide ores, in some hydrometallurgical processes, in the treatment of ores containing radioactive elements, in the preparation of certain industrial minerals, and in the electroplating industry. Table 1 clearly pasteurises the pollution problems in metallurgical industry. In metallurgical plants, a variety of metals, aqueous solutions, gases, dust, molten slags, etc. are produced. Therefore, a knowledge of the hazard involved and the threshold limit is essential.

Table 1: Pollution problems in the metallurgical industry

Industry	Problems
Iron and steelmaking	Gases in coke production, slags, blast furnace, cyanides, electric furnace dust, pickle solution
Ferroalloys production	Arsine and phosphine, silica dust
Aluminium industry	Mercury, red mud, fluorine compounds, toxic organic compounds, cyanides
Sulphide ores: copper, lead, zinc, and nickel	SO_2, mercury, selenium, arsenic
Hydrometallurgical processes: gold, silver, copper, and zinc	Arsine, phosphine, cyanides
Radioactive ores: uranium and thorium	Radon gas (radioactive)
Industrial minerals: coal, phosphate rock, ilmenite, asbestos	Sulphur, ash, trace metals, nitrogen oxides, phosphogypsum, waste acid, toxicity of fibres, tailings
Electroplating industry	Chromium, copper

Pyrometallurgy

Pyrometallurgical processing of ores produces dust, slag, and gases. Dust emission may represent a considerable cost to the plant itself, because of the loss of particles which are sometimes valuable. The problem of dust has been practically solved by introducing dust-catching equipments such as, cyclones, scrubbers, and electrostatic precipitators. Slags are produced in large amounts out of which, only a fraction is used in road construction and in the manufacture of cement. Picture 3 shows a pyrometallurgical plant showing a huge pile.



Pic. 3: Typical view of a pyrometallurgical plant showing a huge slag pile

Hydrometallurgy

Treatment of ores by wet methods produces residues and waste solutions. While slags are relatively stable in outside storage, residues filtered off aqueous solutions are not, because they usually contain soluble ingredients. Hence, disposal in ponds may be hazardous because of the danger of contaminating surface waters unless they are properly constructed. Also, liquid effluents containing toxic reagents must be treated before being discharged in streams.

Electrometallurgy

The most important electrometallurgical operation is in the aluminium industry which emits gases and dust and is presently undergoing intensive improvement. Copper electro-refining and zinc electro-winning also have pollution problems, but these are manageable.

Controlling Factors

Chemical Industry

Chemical industries producing basic bulk chemicals have strong impact on environment. Now a days, novel and efficient technologies and processes have developed, which save raw materials and energy, as well as those involving by-product use and recycling are beneficial for both processes efficiency and environment protection by reduction of emissions in air, water, and soil. This approach is known as the environmentally sustainable industrial development (ESID), leading to reduction of consumption of natural resources and to lessen damage to the environment during raw material extraction. ESID also leads to lower energy demands and consequent indirect decrease in fuel consumption and environment pollution, reduction of emissions in all of the components of the environment and therefore, to the reduction of waste treatment costs. The pollution control techniques for traditional manufacturing processes such as, production of sulphuric acid, nitrate-based fertilizers, soda and caustics, dyes and dye intermediates, pesticide industry as well as bulk drug manufacturing Industry are discussed below.

Sulphuric Acid Plant

The reduction of SO_2 content in the exhaust gases could be improved by adding an intermediate cooling. Mist is formed by small droplets of sulphuric acid in the gases leaving the absorbers. The mist may be formed due to the presence of water vapour in the feeding air. This source of humidity could be neutralised by washing the inlet air with concentrated sulphuric acid. When the acid is not concentrated enough, additional mist formation could take place. Mist formation is usual also, when the sulphuric acid plant is set on run. Reduction of these

emissions could be attained by washing with water or ammonium hydroxide (NH_4OH) in a scrubber. The produced ammonium sulphate ($(NH_4)_2SO_4$) is a by-product, which could partially cover the costs of the emission control. However, the most exploited equipment for mist removal is the Brinck's demister, containing fabrics of glass fibers. The main source of solid waste in sulphuric acid production is the spent catalyst, containing vanadia. The first layer of the catalyst is mostly subjected to destruction and contamination with dust. The regular cleaning and replacement of the spent catalyst is considered to be sufficient for the maintenance of stable operations. The spent catalyst and its dust are collected and shipped for extraction of vanadia and recycling. Scrubbing of the non-reacted SO_2 is usually accomplished by water and ammonia solution. The obtained ammonium sulphate as a by-product, could partially cover the costs for the pollution control.

Nitrates-containing Fertilizers

Nitrates-containing fertilizers were the most frequently used ones in the past. Mainly, they are potassium, sodium and ammonium salts of nitric acid.

The source of pollution is NO_2, resulting from partial oxidation of atmospheric nitrogen at combustion of reforming fuel, as it happens at the combustion of any fuel. Additional part of NO_2 is obtained from partial oxidation of the produced ammonia. This problem can be minimised, when the reforming process is optimised, i.e. to reduce the excess of the air and to improve the process control. Release of produced ammonia is possible too. Measures for restriction of this process are taken, consisting in removal of these products from the exhaust gases, better feeding and compressing of ammonia, as well as an improved control on evaporation in the reservoirs. Realistic amounts of released ammonia are 1 - 1.5 kg/tonne.

The main water pollutants, resulting from ammonia production are the heated water effluents and diluted ammonia-containing waters. Organic compound could also be present. The latter is a result of condensation. The solution of these problems is in the secondary use of the heated effluents for heat UNESCO - EOLSS utilisation. Ammonia could be stripped by steam, or used directly as fertilizer.

The release of the waste gases from fertilizer plant is used to move a turbine for energy utilisation. Hence, about 40% of the energy demands for air compression.

Soda and Caustic Industry

There are 40 units manufacturing caustic soda in India with an installed capacity of 2.27 million tonnes per annum. Actual production in the year 1998 had been about 1.49 million tonnes. 34% of the capacity is based on the mercury cell process, and 66% on the membrane process. The major environmental problems posed by this industrial sector is from the mercury cell process and although this metal is not supposed to get consumed as per the chemistry of the production, it gets entrapped into the circulating brine solution and all the product and by-product streams. This leads to contamination of the water and wastewater, air, and solid wastes generated from the production activities. Also, since the quantity of mercury involved in the production is very large, its leakage, spillage and even evaporation of the spilled mercury are observed to be very common and require proper and timely attention. Therefore, the commissioning/expansion of caustic soda units based on mercury cell process, has already been banned by the Government and the existing mercury cell based plants are also in the process of switching over to the membrane process. However, there is no mandatory target existing for this conversion and the mercury cell based units need to take proper attention for their mercury bearing wastes including the disposal of the brine sludge.

Dyes and Dye Intermediates

Dyes and Dye Intermediates industry is an important sector of the Indian Chemical Industry. The pollution that accompanies this industry in its nature and extents is particularly because of the non-biodegradable nature of the dyes as well as due to the presence of acid/alkali/toxic trace metals/carcinogenic aromatic amines in the effluents. In addition to effluent, gaseous emissions such as, SO_2, NOx, NH_3 & HCL and solid wastes in the form of iron sludge, gypsum and sludge from treatment facilities are generated. Possibilities for adaptation of cleaner process opts for reducing the water consumption and effluent generation; better management practices for segregation and reuse/recycle of the treated effluent; effective utilisation of raw materials; improvement in efficiency of process; and recovery of by-products. The effluent generated from manufacturing of some of the dyes and intermediates such as, H-acid is not bio-degradable, which requires process change. Properly designed scrubber with recovery reuse of scrubbed liquid is required.

Pesticides Industries

Pesticides manufacturing involves various toxic chemicals as raw materials and a number of unit operations, to get required technical grade product. In a unit process, due to impurities in raw materials, variations in operational parameters of the reactor vessels and thermodynamic limitations, 100% conversion of raw materials into products is impracticable. Hence, excess chemicals are fed into the reactor to get the required efficiency and quantity of final product. The unconverted reactants from each unit process generate wastes in the form of effluents, emissions and solids. Hence, some of the controlling factors

are - highly organic streams (toxic effluents) which cannot be treated biologically are to be chemically treated or incinerated, depending on calorific value, process optimisation/automation to avoid discarded products and to reduce pollutants generation, stack gas scrubbing and/or carbon adsorption (for toxic organics) and baghouses (for particulate removal) - all are applicable and effective technologies for minimising the release of significant pollutants to air combustion devices (incinerator) should be used to destroy toxic organics.

Bulk Drug Manufacturing Industry

Environmental pollution control in bulk-drug manufacturing industry requires high skilled manpower due to its nature of pollutants. In general, it has been observed that the final product's purity is of major concern to the industry. Thus, the rejects (unreacted/converted portion of raw materials) contribute to the major pollution load from the industry. So, salt recovery from high TDS or total dissolved solids (inorganic) containing streams through forced evaporation system is required. Some other controlling factors are, properly designed chlorine storage facility with automatic control equipment, collection of fugitive emissions from the processing sections and loading/unloading sections through hoods and ducts and providing control equipment such as, absorption/adsorption systems, multi-cyclones or bag filters for control of emissions from boilers, continuous monitoring equipment/sensors to be provided, etc.

Mining and Metallurgical Industry

Mining

There are a number of ways to reduce the environmental impacts of mining. Some of them are:

Reducing the consumption of minerals

One way to limit the impact of mining on the environment is to consume less, so that fewer minerals are needed to build products like cars, appliances, electronics, etc. This can be accomplished through more efficient resource use, and also by simply using less and recycling more.

The efficiency of manufacturing processes can be increased to reduce the amount of new minerals required

Nations and businesses are discovering ways to use materials more intelligently to provide the goods and services people want, using much less wood, metal, stone, plastic, and other materials. By reducing wasteful use, and by steering production toward durable goods that are easy to reuse, remanufacture, or recycle, a few pioneering firms are recasting the role of materials in our lives. Some businesses have even shifted out of manufacturing and become purveyors of services, dramatically lowering levels of materials use. This creative trend stems from recognition of the environmental costs of excessive materials use.

Substitution of other materials and processes with more environmentally friendly materials and processes

For example, plastics might be used instead of metal to build appliances. Or biomass can be used instead of uranium to produce energy.

Using recycled materials instead of mined materials

Recycling has a number of advantages. For example, it takes far less energy to recycle discarded materials than to extract, process, and refine metals from ore. It takes 95% less energy to produce aluminium from recycled materials rather than from bauxite ore. Recycling copper requires seven times less energy than processing ore; recycled steel uses three-and-a-half times less.

Improving environmental performance at mines

Mining moves enormous quantities of earth: altogether, it strips more of the earth's surface each year than natural erosion by rivers does. Very little of this material is actually used, for example, on an average, some 220 tonnes of earth are excavated to produce just a tonne of copper. Mining also uses large amounts of chemicals in processing and results in significant emissions to air and water. By systematically examining environmental impacts and adopting measures to mitigate these impacts, it is possible to make mining less destructive to the environment.

Legislation and regulations to reduce environmental impact can be enacted and enforced

Governments can require mines to adopt increasingly effective environmental procedures and invoke penalties for failure to comply.

Cleaning up abandoned mine sites

Companies and governments can be held accountable for abandoned sites and be required to carry out an environmental cleanup.

Economic measures

Tax shifting can be introduced to provide incentives for practices like product substitution and disincentives for poor environmental performance.

Metallurgical Industry

- Emissions of irritant and corrosive gases like SO_2, hydrogen sulphide (H_2S) and hydrogen chloride (HCL) may contribute

to air pollution and cause corrosion of metals and concrete within the plant and in the surrounding environment. The tolerance of vegetation to SO_2 varies, depending on the type of forest and soil. In general, evergreen trees tolerate lower concentrations of SO_2 than deciduous ones. Particulate emissions may contain non-specific particulates, fluorides, lead, arsenic, cadmium and many other toxic metals. Wastewater effluent may contain a variety of toxic metals, sulphuric acid and other impurities. Solid wastes can be contaminated with arsenic, lead, iron sulphides, silica and other pollutants

Smelter management should include evaluation and control of emissions from the plant. This is a specialised work which should be carried out only by the personnel thoroughly familiar with the chemical properties and toxicities of the materials discharged from the plant processes. The physical state of the material, the temperature at which it leaves the process, other materials in the gas stream, and other factors - all must be considered when planning measures to control air pollution. It is also desirable to maintain a weather station, to keep meteorological records and to be prepared to reduce output when weather conditions are unfavourable for dispersal of stack effluents. Field trips are necessary to observe the effect of air pollution on residential and farming areas.

SO_2, one of the major contaminants, is recovered as sulphuric acid when present in sufficient quantity. Otherwise, to meet emission standards, SO_2 and other hazardous gaseous wastes are controlled by scrubbing. Particulate emissions are commonly controlled by fabric filters and electrostatic precipitators.

Large amounts of water are used in flotation processes such as, copper concentration. Most of this water is recycled back into the process. Tailings from the flotation process are pumped as slurry into sedimentation ponds. Water is recycled in the process. Metal-containing process water and rainwater are cleaned in water-treatment plants before discharging or recycling.

Solid-phase wastes include slags from smelting, blowdown slurries from SO_2 conversion to sulphuric acid and sludges from surface impoundments (e.g., sedimentation ponds). Some slags can be reconcentrated and returned to smelters for reprocessing or recovery of other metals present. Many of these solid-phase wastes are hazardous wastes that must be stored according to environmental regulations.

Some important examples are given in the next column:

Steel Industry

India is in the race to increase the annual steel production in the country and thereby increasing the per capita consumption. Government of India has plans to augment the total production capacity of steel in the country taking it to 300 MT by the year 2025. Now, India is producing around 76.6 MT per annum of steel associated with emission of CO_2 to the extent of 230 MT. This level of CO_2 emission has reached an alarming stage which has taken away the sleep of many scientific communities who are constantly in search of better technological opportunity. But the sad story is that production of steel is inherently associated with emission of CO_2 as carbon is used as a reductant in the existing conventional process. For inclusive growth and environmental sustainability, researchers are on the lookout for a novel reductant which can reduce iron oxide (Fe_2O_3) to produce steel with zero or near zero emission of CO_2.

CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, Odisha, India has developed a state-of-the-art technology to produce steel with no emission of CO_2 which is called "Green Steel" by hydrogen plasma smelting route and this has been patented already. Moreover, water is produced as a by-product which can be recycled during the production of steel in tonne scale. It is possible to produce iron of 99.54% purity by this process with no emission of CO_2.

Chromite Over Burden (COB)

The overburden of chromite mines and nickel (Ni) laterite is the only source of nickel available in the Sukinda valley of Odisha. The waste overburden is produced in large quantity to the extent of 10 million tonnes per year during the mining of chromite ore. This overburden generates huge volumes of seepage water and severely contaminates the nearby water bodies by siltation and leaching of Cr (IV). Overburden generated is in fine form waste and causes air pollution and ecological imbalances. This overburden has nickel content that ranges from 0.5%-0.9%. This ore has not been commercially exploited due to low percentage of nickel and found that chromite overburden is unsuitable for Fe-Ni making because of very high Fe/Ni ratio and efforts are made to extract valuable Ni, Fe in the form of Fe-Ni. Nickel is found predominantly in two types of ore bodies - sulphides and laterites. Sulphide ores occur as layers and lenses of ultramatic rocks while laterite ores occur due to the weathering of ultramatic rocks. COB ore of Sukinda valley comes under the second category. The primary mineral phases in the COB ore are quartz, goethite and limonite in association with other minor phases like magnetite, hematite, chromite, etc. The nickel contained in lateritic nickel ores does not occur in an identifiable mineral. It is generally accepted

that these ores are not amenable to beneficiation. For this reason, such ores are either directly smelted or leached to extract the nickel. So, in the present work an attempt has been made to enhance the nickel content in pyrometallurgy route i.e. reduction roasting by pan sintering, followed by magnetic separation and plasma smelting. In COB sample, Ni content is very low i.e. 0.65%-0.75% where as Fe is 50.27%. It is found that Ni content is enriched from 0.7% to 1.32% by reduction roasting and further enriched to 1.45% Ni by magnetic separation. The magnetic fraction can be used as raw material for high grade Fe-Ni production.

The enriched COB is smelted in 30kw extended thermal reactor to form immiscible layers of slag and metal by varying basicity, time and using appropriate reductant. The obtained ferro-nickel alloy contains 8% to 10 % Ni. The remaining iron and other metal values including chromium and nickel present in slag, are removed in the form of alloyed pig iron by plasma smelting process and the slag can be utilised as a raw material in cement making. The novelty of the present investigation on the chromite overburden, is a process technology involving pan sintering, magnetic separation followed by two stage plasma smelting processes for obtaining three products: (i) Fe-Ni alloy contains 8 to 10% nickel, (ii) alloyed pig iron for steel industry and (iii) slag for cement industries. Thus, the present technology can be said to be "Zero Waste" which developed an environmental process for the treatment of waste to recover the metal values for the steel industry.

Conclusion

The challenge for technological innovation to control pollution in chemical and metallurgical industry is of prime importance in the field of industrialisation all over the world. The human life is precious and material prosperity should not create problem for its growth and sustenance. In our opinion, industry in close collaborations with the research organisation should streamline research programme to face this challenge.

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Development of Mineral Based Industries in Odisha

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For the last four decades, it has been my pleasure to have been intimately connected with the development of industries in Odisha. As Odisha has got vast natural resources, the process of industrialisation mainly centres in developing vital industries on its mineral wealth. In our State, 3,300 million tonnes of iron ore, 43 million tonnes of manganese ore, 100 million tonnes of chromite ore, 65 million tonnes of nickel ore, 2,000 million tonnes of bauxite, 2 million tonnes of vanadium ore, 30,000 million tonnes of coal, 700 million tonnes of limestone, 360 million tonnes of dolomite, 50 million tonnes of mineral sand, 35 million tonnes of china clay and 62 million tonnes of fire clay are available.

In order to accelerate the industrial growth of the State, Industrial Promotion and Investment Corporation of Orissa Limited (IPICOL) was created for promotion of medium and large scale industries. The Corporation came into existence in 1973. After its inception, the State has witnessed rapid growth of industries in the medium and large scale sectors. During span of 16 years of its existence, it could catalyse about 182 medium and large scale industries in various parts of the State. The major industries promoted are sponge iron, paper, fertiliser, refractory units etc. Similarly, Industrial Development Corporation (IDCOL), a State Government undertaking came into existence in the year 1962. During its 25 years of existence, it has provided the basic strength for industrialisation of the State. Most of the industries promoted base on the utilisation of State natural resources. These are Kalinga Iron Works based on the iron ore deposits in Joda area, Ferro-chrome plant based on the chromite ore deposits in Sukinda area, Cement plant based on the limestone deposits in Dungri area. Orissa Mining Corporation, which is the oldest Corporation in the State has during the last decades, established Ferro-alloy plant at Bamnipal based on its own chromite ore and chrome ore beneficiation plant at Kaliapani.

In private sector, Ferro-alloy Corporation, Ispat Alloy, Indian Metal and Ferro-alloy Limited have established Ferro-silicon, Ferro-chrome units in Choudwar, Theruvalli, Randia and Balasore.

During 1970-80, tests have been conducted in Norway with the assistance of Unido with our vanadium and nickel ore from Rairangpur and Sukinda area. These tests have proved that the ore is suitable to establish these vital Ferro-alloy projects. Similarly, with our high-grade iron ore, tests have been conducted in our country and abroad for the manufacture of sponge iron. On the basis of these test results, two sponge iron plants have already been established in Keonjhar district. IPICOL role in promoting these projects is noteworthy. Recently, these test results have been compiled in a book titled "Technological Excellence of Odisha Industrialization" published by ISR Infomedia Pvt. Ltd., Kolkata.



The industrialisation of the State cannot be compared with States like Maharashtra, Gujarat, Tamil Nadu or Karnataka. The two prime reasons are lack of entrepreneural talent and a sound market base. Hence, the industrial climate is to be stimulated by attracting entrepreneurs from outside the State and setting up large scale industries under central and private sectors which would create mother industries for the growth of ancillary and downstream projects. Realising this, the State announced recently very pragmatic and liberal industrial policy with package of assistance to attract the entrepreneurs from outside the State. For last two years vigorous efforts are being made in getting more central sector projects.

IDCOL and IPICOL have contributed a lot for realisation of some of the central sector projects. Talcher Fertiliser plant was initially planned to be taken up in the State sector and for this, lot of tests were conducted with the Talcher coal. Similarly for bauxites in Koraput, IPICOL initiated lot of

investigations with the help of Indian Bureau of Mines. These preparatory work ultimately led to the establishment of the Fertiliser plant at Talcher and Alumina plant at Damanjodi. In Paradeep, IPICOL assisted Madras Fertiliser to prepare the project report for Paradeep Fertiliser plant which has already been realised with the help of Nauru.

Apart from the Corporation, the development of resource-oriented industries has been pioneered by some of the dedicated officers and professional in Government and the Corporation. To them, we owe special gratitude. In techn-economic front, these projects may have suffered temporarily but ultimately have provided the basic strength in technology and finance for the industrialisation of the State.

The twelfth plan is about to start next year. It is the time that we must concentrate to develop some of the resource-oriented projects of national importance to be undertaken by the Government or private agencies. Some of these projects are mentioned below :

1. Ferro-Nickel utilising Sukinda nickeliferrous ore.
2. Ferro-Vanadium on the basis of vanadium bearing ore in Mayurbhanj district.
3. Special alloy steel project utilising liquid Ferro-chrome and Ferro-nickel as major inputs.
4. Electrolytic manganese dioxide and metal project based on the manganese ore of Keonjhar district.
5. Titanium sponge and dioxide units based on mineral sand in Ganjam district.
6. Graphite processing unit in Kalahandi district.
7. Tin ore processing unit in Koraput district.

In conclusion, it may be worth pointing out two basic aspects of development from national point of view.

i) All resource-oriented industries from techno-economic point of view may be planned not to produce intermediate product like charge chrome all the time but should diversify for production of end-product like special steel where the cream of the profit lies. This will also help best utilisation of the energy.

ii) States like Odisha, Madhya Pradesh, Bihar etc. where there are large concentration of natural resources should enjoy some priority in ihe developmental planning in the sense that Industrial belts should be identified for growth on the basis of an integrated approach of Power, Water, Communication and Mineral wealth. Projects should be implemented in a phased manner to maximise the utilisation of infrastructure on which nation has already invested a fortune.

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The Missing Link in Odisha Industrialisation Programme

Dr. Ing. H. P. Mishra
Ex-Chairman, IPICOL, Bhubaneswar

For last few decades after 1970, our state has promoted some vital mineral based industries especially in Iron & Steel, Ferro Alloy, Alumina & Aluminium sectors. These industries will provide infrastructure for promoting industrialisation, but real industrialisation will be measured how much of these basic metals is getting converted to technological products through mega, medium and small scale industries with value addition and employment generation.

For changing the present status, few points have been mentioned which may be analysed in due course.

In our present industrialisation programme, for converting mineral resources to basic metals like iron & steel, ferro alloy and alumina & aluminium etc. Besides the mineral, water, power, human resources are used. The metallurgical process entails pollution, degradation of forest area and utilisation of scarce water resources.

The profit margin available in these, if computed, is marginal. However, the availability of these basic metals is essential to utilise technological knowledge and human skill for high value technological product required nationally and internationally.

The real industrialisation will be measured how much of these basic metals is converted to these products as in case of China where technological knowledge and skill form the major input.

For creating these, different projects should be planned in the steel corridor which encompasses basic metal producing units. Industrial projects should be developed facilitating industries in medium and small scale sectors of high value utilising technical qualified personnel available from different institutions and industries.

Besides these, dedicated industrial parks should be developed preferably in the industrial corridor with excellent connectivity to Paradip and Dhamra Port facilitating national and international trade.

Furthermore, plans should be made to promote Technology Development Centre in which semi-commercial units can be installed and can be operated continuously providing data for installing commercial plant. This will bridge the gap between research laboratory and industrial units and will facilitate manufacture of ferro nickel, ferro vanadium etc. from our mineral waste as in case of sponge iron during 1980.

Basic metal producing units are enough but real industrialisation will usher when secondary basic metal producing units are programmed where our skilled workers will be gainfully employed with value addition to nonreplenishable mineral resources to meet the national requirement and international trade.

Dr. H. P. Mishra conferred with Kalinga Samman Award 2013



Dr. H. P. Mishra receiving Kalinga Samman

Eminent metallurgist and Founder Chairman of IPICOL, Bhubaneswar, Dr. Hara Prasanna Mishra has been conferred with the 'Kalinga Samman Award-2013'. Dr. H. P. Mishra has received this honour for popularisation of science in Odisha, India.

This award was presented by Hon'ble Chief Minister Naveen Patnaik, of Odisha, at a function at Institute of Physics, Bhubaneswar organised by Kalinga Foundation Trust on 15th September 2014 at which Hon'ble Minister, Science & Technology and Higher Education, Govt. of Odisha Dr. Pradeep Kumar Panigrahi; Chairman of Kalinga Foundation Trust & Ex-M.P. Bhabani Charan Pattanayak; Managing Trustee of Kalinga Foundation Trust & Hon'ble Ex-Minister Prafulla K. Samal, Advisor to the Department of Science and Technology, Govt. of India Dr. (MRs) Ahuja, were also present.

Dr. H. P. Mishra has earned his M.Sc. in Applied Chemistry from Calcutta University and Doctorate in Engineering from Technical University of Aachen, West Germany. He has started his career way back in the year 1951 and worked for various leading organisations. From 1951 to 1955 he has worked as a Senior Chemist in the Fertilizer Corporation of India. Then, from 1955 to 1964, he was Officer-in-Charge of By-Product Plant and Fertilizer Plant, Rourkela Steel Plant of the then Hindustan Steel Limited (HSL). He was Technical Advisor & Chief Executive Officer, Industrial Development Corporation of Odisha Limited (IDCOL) & Additional Secretary, Industries Department and Industrial Advisor to the Government of Odisha from 1964 to 1967. He served as a Chief Superintendent of Bokaro Steel Limited from 1967 to 1969. He worked as a Managing Director of IDCOL from 1969 to 1974. He was Founder Chairman of Industrial Promotion and Investment Corporation of Orissa Limited (IPICOL) from 1974 to 1984. He was also a Resident Director of M. N. Dastur & Company Limited at Bhubaneswar in 1984.

Dr. Mishra is a Member of Kalinga Institute of Technology & Design (KITD) from its inception for development of advanced technology & design for industrial renaissance of Odisha. He is a Life Member & Fellow of a Host of Professional Bodies both in the country & abroad and is actively engaged in development of metallurgical profession in the country. He is also a Senior Member of American Society of Chemical Engineers, USA which is considered as a matter of pride for a professional metallurgist.

Dr. Mishra has been bestowed with large number of awards & accolades for his significant contribution to Chemical & Metallurgical Profession and he has published large number of research papers, technical and popular science articles which have brought him into the industrial limelight in the global perspective.

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The Importance of Promoting Down Stream Industries for Industrialization of Odisha

Dr. H. P. Mishra
Ex. Chairman, IPICOL, Odisha

During my long tenure nearly sixty years in getting associated in industrialization of our state, I have come to conclusion, time has come to seriously plan how our industrialization programme will cater to these basic requirement of our state especially in mineral sector.

1. You will kindly appreciate our mineral resource gifted by the Almighty is not replenishible in contrast to Agriculture and other resources. Its exploitation, value additions and providing useful employment to our people especially to skilled people should be carefully planned and implemented.
2. Our industrial activities at the present stage of Industrialization must address to the pollution problem affecting our people. We must ensure the industries we are planning to build effectively take care this aspect.
3. In planning mega industries...Steel, Sponge, Ferro Alloys, Alumina, Aluminium and Titanium etc., Government at this stage of our development must ensure the basic metal produced is utilized creating downstream industries producing value added products and provide sufficient incentive for promotion of Medium and Small Scale Industries which will create jobs for our skilled and unskilled workers.

In our state we have mega steel industries like Rourkela Steel Plant, Kalinga Nagar Industrial Complex with mega Steel Projects of NINL, TISCO, VISA, MESCO etc., Steel and Aluminium complex in Angul and Jharsuguda Industrial area, Indian Rare Earth Project in Gopalpur, upcoming Steel and Refinery project at Paradeep, Ferro Alloy Projects in Cuttack and Koraput districts and the Aluminum Complex in Koraput district. Now the primary aim of the entrepreneurs is to export the basic metal to other state of our country to make money for their organization. I feel it is high time that they should be persuaded for setting of high value technological projects. Real industrialization can be measured in my understanding as to what percentage of this basic metal is converted for value added product specially required for our country with the

expansion of Technical Education in our current plan period and projected in twelfth plan period. In near future, our Country in the world will be one of major source of skilled manpower. We must ensure jobs for them by expanding our Medium and Small Scale Industries to create new generation of entrepreneurs acquiring not only commercial but technical and entrepreneurial skill also. In the world today innovative skill largely provides strength for competition in global market. These MSME along with Technical Institutions will provide platform for our students to make innovative efforts for new products to cater to the National and International requirements.

In my dream for industrialization of our state for last three decades, we have conceived industrial belts connecting Paradeep-Kalinga Nagar area, Angul- Jharsuguda-Rourkela and also Kalinga Nagar to Keonjhar and Barbil area. Similarly in Koraput district, based on Bauxite deposit, industrial belts need to be developed. These industrial belts will have water sources from rivers like Mahanadi, Brahmani and Baitarani etc. and Coal deposit in Talcher and IB Valley area. Proper planning should be worked out to improve connectivity by Road, Railways. Dams in rivers for storing water to be used for our industries for mega thermal power generation. In these belts, land should be acquired in the vicinity of major industrial units to develop industrial parks for accommodating Medium and Small Scale units which will utilize basic metal for value added products.

In conclusion, I feel creating some mega Steel, Alumina & Aluminium Plants will not fulfill our programme for industrialization. This may bring immediate profit to entrepreneurs but at the cost of valuable non-replenishible minerals, water and power source. In our state we have already sizeable production of the basic metal from the mega industries. In my opinion, real industrialization will be measured what percentage of this basic metal is used in promoting mega, medium and small scale industries for producing technological products for house hold appliances, electronic, automobiles and many other sectors.

We must conserve our minerals for the purpose for our coming generation and prepare a planned programme with the help of reputed professionals and consultants. My suggestion is that Government must create a 'Task Force' for the purpose and a proper planned document detailing out time bound activities for the purpose is to be prepared for the necessary action in this direction.

■

Vision on Industrialization of Odisha

Dr. H.P. Mishra
Ex. Chairman, IPICOL, Odisha

I would like to bring some of the points for kind attention of Hon. Chief Minister of Odisha Sj. Naveen Patnaik regarding the industrialization of the state;

1. The real industrialization can be measured by utilization of basic metals to various types of products by using the technological knowledge of high quality manpower.

2. It needs industrial corridors at different locations to set up downstream and upstream small and medium scale industries of major metal industries to produce various types of products where the cluster growth of industry can be realized over a period.

3. Mineral resource should be used judiciously because these are non-replenishible. It should not be misutilized only by mining activity. The resource should be utilized by value addition till the end products.

4. For industrialization of Odisha, new generation of entrepreneurs should be created, those who have technical knowledge through venture capital.

5. IPICOL should be strengthened with high quality technical manpower.

6. Technology Development Centre should be set up by Govt, of Odisha in association with R&D and academic organizations to solve the bottle neck of the processes of existing industries and simultaneously to develop the advance process to utilize the low grade mineral resources.

7. Human resource development in the state should be given the top most priority to produce quality manpower in proper engagement in our industrialization sectors.

8. Port facilities at Paradeep, Dhamara and Goplapur should be improved further as well as create new ports in long marine drive for import and export of the materials.

9. Infrastructure facilities like road, railways, even pipeline corridors for transportation should be made in high quality to attract more entrepreneurs for investment.

10. Power sectors should be improved to make their stability for undisturbed power supply to industries as well as people.

11. Chemical industries like chloro-alkali, fertilizer and food processing industries should be encouraged.

12. Major wastes i.e., red mud, gypsum, iron ore tailings, fly ash etc. should be given priority to make value addition to keep the environmental balance of the ecology. If required, incentive provision should be made.

13. Water harvesting should be done by Public Private Partnership (PPP) mode in the river itself so that both agriculture and industry can survive together.



Vision for Developing Mineral Resources and Industrialization of Odisha

Dr. H.P. Mishra
Former Chairman, IPICOL Odisha

INTRODUCTION

Former President, Dr. A.P.J. Abdul Kalam always mentioned that for a country to grow people must learn how to dream in a big way. In our journey for establishing mineral based industries, innovation is the keyword to be competitive in national and international sector. To sustain the process of industrialization, professionalism at every stage of our operation is extremely important.

Endowed with plentiful reserves of valuable ores and minerals, it was expected that Odisha would emerge as the leading industrialized state of the country.

The mineral resources of the State can be considered under four categories namely.

1. Those which are currently being mined like iron ore, manganese ore, chromite, bauxite, coal, limestone, dolomite, mineral (beach) sand.
2. Those which were mined in the recent past but currently suspended such as china clay, fireclay, graphite, gemstones, kyanite, soapstone, asbestos.
3. Those which have potential for development like nickel ore, PGM, gold, tin ore, vanadium bearing magnetite, base metals, diamond, atomic minerals, oil and gas.
4. Host of minor minerals like granite, quartz, serpentines, feldspar.

LOOKING BACK

The industries set up during the early years of the last century, 1950s and 1960s were a few and dispersed. These include

- Aluminum Smelter at Hirakud
- Refractory Plant at Belpahar.
- Ferromanganese plants at Rayagada and Joda, Low shaft pig iron plant near Barbil
- Graphite Crucible Plant at Titilagarh

- FeCr Plant at Jajpur Road
- Cement and Refractory Plants at Rajgangpur
- Refractory Plant at Latikata.
- Fertilizer Plants near Rourkela and Paradeep
- FeSi Plant at Theruvali
- The First Integrated Iron and Steel Plant in the public sector at Rourkela.
- Coal based Thermal Power Plants in Talcher and Ib river coal field areas and Choudwar.

Later years witnessed commissioning of:

- Charge Chrome Plants near Bhadrak, at Brahmanipal, Choudwar, Theruvali & Meramunduli.
- Cement Plant near Bargarh
- Mineral Separation Plant of IREL at Matikhal
- Host of Mini Cement Plants (since closed)
- Host of Sponge Iron Plants (most of which are not in operation)
- Alumina Refinery at Damanjodi and Smelter at Angul of Nalco.
- Alumina Refinery of Utkal Alumina at Doraguda
- Alirmina at Lanjigarh and Smelter at Jharsuguda of Vedanta
- Iron and Steel Plant of MESCO near Jajpur Road
- Stainless Steel Unit of Jindals in Kalinga nagar
- Iron and Steel Complex of Bhusan Steel in Jharsuguda.

Recent development in the industrial sector in the State includes:

- Commissioning of 3 million tonnes / year integrated Iron and Steel Plant of TATA Steel in Kalinga Nagar in the first phase as a part of ultimate 6 million tonnes / year capacity.
- Oil Refinery at Paradeep.
- Expansion of Rourkela Steel Plant of SAIL (4.5 million tones of hot metal, 4.2 million tonnes of crude steel and 3.9 million tones of saleable steel). The capacity of Rourkela Steel Plant is planned to rise to 10.8 mtpa by 2025, though appears ambitious.
- Expansion of Nalco (Mines, Refinery and Smelter)
- Iron and Steel Complex of Jindals in Angul area.
- Ferro - Chrome Plant of Tata Steel near Berhampur.

(The list is not exhaustive and some might have been missed)

INFRASTRUCTURE

In the infrastructure front, the following projects are of significance for growth of mineral based industries in the State.

1. Hydel Projects at Machhakund, Balimela, Rengali, Kolab and Indravati
2. Commissioning of Paradeep and Dhamra Ports.
3. Rail Links
   a) Banspani-Jakhpura
   b) Bailadila- Kottavalsa
   c) Sambalpur-Talcher
   d) Barsua- Rourkela
   e) Kiriburu- Bimlagarh- Bondamunda
   f) Bolani- Barbil
   g) Banspani- Padapahar
   h) Bhadrak- Dhamra
   i) Rayagada- Bhawanipatna
   j) Rayagada- Jeypore- Jagdalpur
4. Road Links
   i. Daitari - Paradeep Expressway.
   ii. Keonjhargarh- Naranpur- Bamanipal
   iii. Panikoili -Bhadrasahi- Koira-Lahunipada- Rourkela
   (Development of this vital NH is continuing at snail's pace. Needs urgent attention of both the Central and state Governments)
   iv. Joda-Bamebari-Palaspanga
   v. Talcher/Angul- Kaniha- Pallahara

This in brief, is the infrastructure set up relating to growth of mineral - based industries in the State. Though relevant, healthcare and education facilities have not been discussed. Suffice to say, these areas call for considerable improvement.

Some of the failures and priority areas that require urgent attention of both State and Central Governments need to be highlighted.

Topping the list is failure of both the State and Central Governments in materializing the 12 mtpa mega steel project of POSCO. Delay in decision

making and particularly delay in granting a lease for iron ore has been the main reason for stalling the project. No foreign steel company would like to have access to an iron ore property through auction.

Next in the list of failures is inability of the State Government to provide required facilities for Mittal's proposed iron and steel complex in Keonjhar district.

The third failure, a major one, is not providing a lease for bauxite to Vedanta Aluminium in spite of assurance. On the basis of assurance given by the State Government, Vedanta set up 1 million tpa refinery at Lanjigarh at an investment of nearly Rs. 4000 crores. Political class and NGOs combined to stall the possibility of supply of bauxite from Niyamgiri although there is absolutely no technological basis for the same. The unfortunate part is that the State Government took a passive role. The least that can be done to save the project from closure is to make available required quantity of bauxite either directly by grant of a lease or through OMC.

Some of the priority infrastructure projects that call for early completion include the following:

Railway Links

- Haridaspur- Paradeep
- Talcher- Bimlagarh
- Angul- Duburi- Sukinda
- Badampahar- Keonjhar
- Jeypore- Malkanagiri
- Bolani- Roxy

Doubling of:

- Banspani - Daitari- Jakhpura line
- Sambalpur-Titilagarh
- Sambalpur-Talcher
- Sambalpur – Jharsuguda

Urgent need for completion of Bhadrasahi- Koira- Lahunipada- Rourkela road link has already been mentioned.

With regard to development of major ports, Gopalpur assumes strategic importance. Water reservoirs can be constructed on Brahmani and Baitarani rivers at favourable locations to meet the requirement of water for the industries in a planned manner. Construction of Kanupur dam on river Baitarani should be expedited.

In the mineral sector, priority should be given to revive the mines where operations have been discontinued and to accelerate the process of exploration inducting expertise and technology from abroad.

Mineral based industries which can come up in the State and those which need revival include

a) Ferro Vanadium and Ferro Titanium
b) Nickel and Cobalt
c) Aluminum Lithium Alloys,
d) Aluminum Silicon Alloys
e) Manufacture of value added products in medium and small scale sector- confined to special alloys and automobile components.
f) Revival of Sponge Iron Manufacturing Units
g) Control of NINL should be vested with either SAIL or RINL to facilitate its growth.

Conclusion

An area of concern is poor law and order situation and negative approach of the NGOs. The State Government should do well to take note of this and remedy the negativism. Finally, I feel, we will have to consciously make efforts to develop technology entrepreneurship that are well equipped professionally. Our promoting organizations like IPICOL, IDCOL and OMC should be staffed with professionals of repute. They must learn to project the enormous potential of the State for industrialization and interact with organizations in India and abroad to bring in the best technologies for adoption in our State. In IPICOL, we should have venture capital fund to assist entrepreneurs who have acquired technological expertise but lack funds back up. Both the State and Central Governments must involve technical and professionals scientists and engineers in decision making process. Then only the State's industrialization process can materialize & see the light of the day.



Personality Extraordinaire



Interview with Shri Satyabadi Satapathy

Founder &First Nalconian and the Brain behind the Giant Aluminium Complex,NALCO

NALCO Samachar, Vol-6, No. 5,
July –September, 1981, pp 8-12



Shri Satyabadi Satpathy, known as the first Nalconian and also the brain behind the giant aluminium complex, is a name to reckon with in Aluminium Industry of the country.

A man of wide and varied experience, Shri Satpathy began his career in 1955 with the Atomic Energy Establishment (now Bhaba Atomic Research Centre) in Bombay. He made his forays into Aluminium Industry in 1957 when he joined Indian Aluminium Company(INDAL) as Technical Officer and spent 15 years in the company. In 1972, he joined Bharat Aluminium Company Ltd. (BALCO), the first Public Sector Aluminium Enterprise, as Chief of Technology. In that capacity he was in-charge of such vital areas as Research, Design, Technology and Planning & Development in the field of aluminium. Shri Satpathy's contribution to the shaping up of BALCO has been praiseworthy.

Shri Satpathy is also credited with conceiving and shaping up the giant complex i.e. NALCO for which he started working right from the day one.

A highly qualified metallurgist, Shri Satpathy has visited several aluminium plants in the world and has organised R&D on aluminium back home. Shri Satpathy has been associated with the aluminium industry for such a long time that he has virtually become an institution. A well-read person, Shri Satpathy takes keen interest in academics. He has written a number of technical articles and reports which have been acclaimed all over the world.

At the time of retirement (1989), Shri Satpathy was working as Director (Technical). He was retained as Advisor (Technology) for one year in view of his distinguished services. It was but natural for NALCO Samachar to talk to such a versatile man and learn from his experience. On a rainy day, our team set out to take him down memory lane.

Samachar :

You are known as the first Nalconian and also the brain behind this giant aluminium complex. You have been very closely associated with this company right from inception. Would you recollect some of the glorious moments of you working in NALCO?

S. Satpathy :

I clearly remember that glorious day (1975). It was a bright Sunday and I was enjoying my morning cup of tea when the All India Radio, Jeypore, announced that bauxite has been discovered in Koraput district. This announcement made me sit up and think. I could visualize the potential for a huge aluminium complex in the state of Orissa. I was really thrilled. Immediately I wrote a 3-page letter to the then Chief Minister, Smt. Nandini Satpathy, explaining the potential of the bauxite reserve. Smt. Satpathy took it up with the concerned Minister in the Centre, Shri Chandrajit Yadav, who, in turn, requested the then Chairman of BALCO, Shri A.N. Banerjee to examine and prepare a report. This was the beginning of the Orissa Aluminium Complex. In the meantime, several meetings were held with the Chief Minister in Bhubaneswar and plans were drawn to prepare a feasibility report.

The Year 1976

I was in the state capital with Shri A. K. Patnaik, DGM(Alumina), Shri R. N. Gupta, Ex. DGM(TS) and Shri Tuli and Shri N. K. Das from State Govt. All of us drove in a jeep to Kakriguma village in Koraput. We were excited with the feeling that we are going to unearth the mystery of Panchpatmali. As we reached the plateau, the vast expanse of the plain hilltop lay stretched before us in its bald majesty. I will tell you two major incidents, fresh in my memory even to-day, which proved quite auspicious. We came across a cow in just giving birth to two calves. The local tribal said, "Babu, two calves mean good omen. You will be successful in your mission". The second good sign was a sudden heavy rain, almost a cloud blast while we were jeeping down the valley. As you know, an auspicious occasion invites rains. However, we had some share of bad luck too as our Jeep got stuck down-hill giving a heart attack to one of our colleagues.

The year 1977

Having prepared the report, we looked around for a suitable technology. We had offers from Alcan, VAW, Pechiney and Alcoa. I met Shri Biju Patnaik, then Union Minister of Steel & Mines, who studied the project thoroughly and suggested to go for French technology. It was a momentous decision.

Regarding Alumina, the issue was whether to go for Atmospheric Digestion or high pressure technology. Initially, I was not in favour of Atmospheric Digestion technology as at that time, only one plant was operating in the world. However, in retrospect, I am delighted that the Atmospheric Pressure technology obtained by NALCO has proved to be efficient and economical. Because of the fact that the Panchpatmali bauxite deposit quality is quite uniform and available in huge quantities.

Another crucial decision was selection of 180 KA technology for the Smelter. At that time, this technology was in pilot stage and yet to be commercially exploited. I visited Pechiney's St. Jean-de-Maurienne where 10 cells of 180 KA were being tested. The Australia Govt. was also negotiating with Pechiney to set up a similar Smelter at Tomago. However, we became the first to obtain this technology. It was quite a risky decision. However, once again, this bold decision has proved to be a good gamble. Our Smelter will continue to enjoy a definite technological edge for the next 10 to 15 years in this part of the world.

Samachar :

What were the most anxious moments for you and your team at the initial stages of the Project?

Satpathy :

It was originally planned to set up the Smelter at Damanjodi near the Alumina Refinery Complex. Since easy availability of power in Koraput was a major constraint we had to look for other options. The most techno-economic solution was to shift the Smelter to Angul which is nearer to the coal belt of Talcher. Though it involved logistic problems, it was considered advisable to transport alumina from Damanjodi to Angul, rather than transport power from Angul to Damanjodi. The proposed captive power plant in built in the project became a serious issue as the State Govt. initially hesitated to sanction the Power Plant. The State Govt. advised NALCO to invest the same amount in the proposed Super Thermal Power Plant at Kaniha near Talcher and draw from there. I was totally against this proposal as I feared that such super Thermal Power Plant might never come up in the near future. I argued with the State Govt. that either you sanction us the power plant or lose the entire NALCO Project. I supplemented my argument with a note of dissent to the Govt. Besides, I wanted the

location of our Captive Power Plant at the present Balaram Prasad, rather than at Kaniha as proposed by the Govt. In a crucial meeting with the then Chief Minister, Shri J.B. Patnaik, I managed to convince him 'let NALCO have its own power plant and let the State Govt. fight for the Super Thermal Power Plant.' And today the results are there for everybody to see. Our Captive Power Plant started generation from 1986 whereas the work on Super Thermal Power Plant began only recently.

Another major problem we faced was getting the clearance for the crucial railway line between Koraput and Rayagada which is considered the life-line of NALCO's Alumina movement both for exports and Smelter. We had some well-wishers like Shri Satakodi Hota in the Railways, who helped us in getting this project cleared and later on implemented by Railways themselves.

Another major challenge was transportation of Alumina over a long distance of 700 Kms. to Angul and 300 Kms. to Vizag. Our requirement was special fluidised wagons which were not available indigenously. Our proposal to the Railways to manufacture the special wagons was initially turned down with a suggestion to go for the traditional oil tanker type wagons. However, with the help of some friends in the Design Institute of Lucknow, we were able to get across our views. A team was formed consisting of Shri CB Agarwal, Chief Engineer, NALCO and a member from the Design Institute who went to France and Germany and finally managed to get a collaboration with Simotra of France. As a result, today, we have been able to reduce the cost of transportation by 1/3rd.



Samachar :

Being incharge of Projects and Technology, you must have encountered some difficult situations.......Would you like to recount some of them?

Satpathy :

With the determination to introduce high tech in all fields of activities in this giant complex, import of equipment and technology became imperative. So the only option left was to reduce the foreign exchange components by arranging collaboration between Indian and foreign parties for maximizing production of vital equipment in India. This was a tough job. Because on one hand the foreign partners were reluctant to part with their technology. On the other the Indian counterparts were totally indifferent to our proposals. But we were not disheartened. I personally went to various companies to motivate them to go for such collaborations which would bring business prospects. Fortunately, after long persuasion, useful collaborations could be achieved. Notable ones are : BHPV with Kestnore, Indian Railways with Simotra, Lurgi with Simone Carves, FLB with Mac Nally Bharat and BHEL with Stein(for Boilers).

Another classic example was development and manufacture of Pot Cells from Pechiney designs in India. After several modifications the cells could be finally manufactured indigenously. Today, the expertise is available within the country and NALCO will not have any problem in procuring these equipment for expansion purposes.

Samachar :

You have been associated



fabrication. It will have to constantly monitor and maintain its standards in the fields of environment and energy conservation.

Finally, NALCO should expand its capacity as soon as possible. I am happy to note that a proposal for a Rs. 2000 crore expansion has been submitted to the Govt. This will give a lot of lever to NALCO. In fact, capacity expansion is in-built in the complex right from the project stage. I do not think NALCO will have any problem in putting another pot line in Smelter or one more stream in alumina plant.

Samachar :

What are the specific things you didn't like in NALCO ?

Satpathy :

Originally, it was planned to set up downstream facilities as part of the NALCO project. However, the proposal was not pushed through. As a result, we missed the bus. Secondly, right from the beginning, we have been giving way to adhocism in our activities to which I was also a party. We should never encourage make-shift arrangement just to please somebody for meeting the targets. We should aim our activities at longterm results.

Samachar :

What would you suggest to improve upon the existing systems and practices—both in technical and administrative management fields?

Satpathy :

NALCO must gear up its R&D activities because that is the most crucial factor today in ensuring continuous and efficient working of the factories. Secondly, NALCO should introduce a strong technical traininig system for its supervisors and engineers. Unfortunately, from the beginning, there has been more emphasis on generalised training confined to few workshops and class room teachings. This does not help in a high-tech industry. Besides, there should be greater thrust on total human resource development rather than casual piece-meal training courses here and there. NALCO will have to take the middle management into confidence and groom them into a disciplined and bold brigade, because it is the middle management that holds the key to higher production and greater productivity.

Samachar :

What do you like most to do in your spare time?

Satpathy :

My favourite past-time is reading technical literature, especially developments in various fields of aluminium industry and related materials. Development in material science is very exciting.

Samachar :

Any message you would like to put across to your colleagues in NALCO, many of whom you know personally so well ?

Satpathy :

One should develop an attachment and concern for any activities he does or intends to do. One may face hostile environment in today's highly complex industrial culture, but one should not detract from one's ultimate goal.

NALCO has a great 'future.' Nalconians should join hands to explore the 'future' for the larger benefits of the country.

Keywords: Ores and Minerals, Waste Management Plan, Eco-friendly Technology, Innovative Practices, Value Addition

State-of-the-art Environmental Management Plan, Practices and Prospects in Major Mineral based Industries





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Odisha is endowed with vast mineral resources like Bauxite, Iron Ore, Chromite, Manganese Ore, Ilmenite and Coal. Based on these mineral resources, various industries have been set up in the state like Alumina-aluminium Plants from Bauxite; Iron and Steel Plants from Iron Ore; Charge Chrome/Ferro Chrome from Chromite; Ferro Manganese, Silico Manganese from Manganese ore; Titanium Oxide from Ilmenite; Coke from Coal; Coal-based Thermal Power Plants etc. These major mineral-based industries during the plant operation produce respective valuable metals along with associated waste materials. The Alumina-aluminium Plants produce red mud, spent cathode port line materials and fly ash from their captive power plants. Iron and Steel Plants produce blast furnace slag, steel scraps, mill scales along with iron ore fines, slimes from iron ore mines. Chromite Plants produce chromium slag and associated Chromite Over Burden (COB) generated during mining of chrome ore. Manganese Plants produce ferro manganese slag and manganese ore fines during mining etc. The Indian coal contains high ash content, which also needs to be beneficiated for industrial use. The Coal-based Thermal Power Plants generate huge quantities of fly ash, which is considered as an environmental menace. All these waste materials generated from major mineral-based industries are to be properly managed and utilized so that wastes can be converted to wealth, adding value to the economy.

A proper waste management plan, environment-friendly operational practices and novel innovative prospects are to be synchronized with the technology so that generation of waste is minimized; the operating process becomes eco-friendly and value addition to the economy is achieved. Furthermore, for achieving better productivity by the application of state-of-the-art technology, plants should be ready to accept any incremental innovative prospects developed indigenously by in-house efforts and through collaboration with the National R&D Institutions.

The state has a strong technology pool, which should be tapped effectively by the industrial houses operating in the state so that a joint technology action plan amongst the Academia, National S&T Institutions and Industrial Houses can be developed for implementation in the Industries to the best advantage of stakeholders.

The present paper describes the importance of waste management plans for mineral-based industries, eco-friendly plant practices for achieving zero waste and prospects for introduction of innovative practices into the body of the technology so that productivity is enhanced; the environment is properly protected and value addition to the economy is achieved.

Introduction

Odisha is now considered as the land of opportunity. It has vast reserves of mineral wealth, forest coverage, water resources, long coastal belt, vast coal reserves, port, air and roadways, sound infrastructural base, hydropower, renewable energy sources, strong academia, IT sectors, hotel and tourism industries, Micro, Small and Medium Enterprises (MSME) etc., over and above backed by age old tradition of majestic art, culture and heritage. Odisha has attracted large numbers of industry players, who have demonstrated their industrial acumen and have set up small, medium and large-scale industries in the state in various sectors. Sound industrial policy of the state, considered as one of the best industrial policies of the country, backed by 'Make in India' plan of the Government of India, which has given a tremendous boost to the industry renaissance of the state.

The state capital Bhubaneswar has earned the rare distinction of being the first smart city out of twenty competitive cities of the country. The state has more than twenty-two Universities, one Central University, IIT, IIM, NISER, IISER, about hundred engineering and technology colleges in addition to a large number of National S&T laboratories viz. CSIR-IMMT, ICAR-NRRI, ICAR-CIFA, Institute of Life Sciences, ICMR-Regional Medical Research Centre, Institute of Physics, AIMS etc. The city of Bhubaneswar is going to be a heritage city of the world under UNESCO. Once known as the city of temples, Bhubaneswar is now considered as the IT capital and educational hub of the nation.

Industries like NALCO, SAIL-RSP, IRE-Chhatrapur, HAL-Sunabeda, Jindal Steel and Power, Bhushan Steel, TATA Steel, ESSAR Steel, VEDANTA, VISA Steel, IMFA, and NTPC have set up their industrial enterprises in the state. In addition to the above, there are large numbers of small and medium players, those who have established their presence in the state in various industrial sectors, adding economy to the state. Large numbers of technologies are in operation in the state today through these industrial ventures, making the state rich in technological operation and practices. Large numbers of scientific and technical manpower are rendering their valuable services to the state, thereby Odisha has established its leading position in the industrial map of the country.

Odisha is endowed with vast mineral resources like Bauxite, Iron Ore, Chromite, Manganese Ore, Ilmenite and Coal. Based on these mineral resources, various industries have been set up in the state like Alumina-aluminium Plants from Bauxite; Iron and Steel Plants from iron ore; Charge Chrome/Ferro Chrome from Chromite; Ferro Manganese, Silico Manganese from Manganese Ore; Titanium Oxide from Ilmenite; Coke from Coal; Coal-based Thermal Power Plants etc. These major mineral-based industries during the plant operation produce respective valuable metals along with associated waste materials. The Alumina-aluminium Plants produce red mud, spent cathode port line materials and fly ash from their captive power plants. Iron and Steel Plants produce blast furnace slag, steel scraps, mill scales along with iron ore fines, slimes from iron ore mines. Chromite Plants produce chromium slag and associated Chromite Over Burden (COB) generated during mining of chrome ore; and Manganese Plants produce ferro manganese slag and manganese ore fines during mining etc. The Indian coal contains high ash content, which also needs to be beneficiated for the industrial use. The Coal-based Thermal Power Plants generate huge quantities of fly ash, which is considered as an environmental menace. All these waste materials generated from major mineral-based industries are to be properly managed and utilized so that wastes can be converted to wealth, adding value to the economy.

A proper waste management plan, environment-friendly operational practices and novel innovative prospects are to be synchronized with the technology so that generation of waste is minimized; the operating process becomes eco-friendly and value addition to the economy is achieved. Furthermore, for achieving better productivity by the application of state-of-the-art technology, plants should be ready to accept any incremental innovative prospects developed indigenously by in-house efforts.

The present paper describes the importance of waste management plans for mineral-based industries, eco-friendly plant practices for achieving zero waste and prospects for introduction of innovative practices into the body of the technology so that productivity is enhanced; the environment is properly protected and value addition to the economy is achieved.

Industrial and Mineral Wastes Generated in Odisha

The mineral-rich state of Odisha has huge deposits of iron ore, predominantly in the tribal regions of the state. Besides Iron Ore (more than 35% of the country's iron ore reserves with 5231 million tonnes of Iron Ore), it counts for 26% Coal and 67.6% Manganese reserves of the country. About 98% of the total proved Chromite (Chromium Ore) reserves of the country, of which 97% occur in the Sukinda Valley, covering approximately 200 sq. km in the Jajpur district, is used for the production of Iron-Chromium alloys (Ferro Chrome). The state has world's fourth largest bauxite reserves with a total deposit of 1805 million tonnes, constituting about 58% of the country's total reserves of the ore, used to make Aluminium. The Mineral Map of Odisha and Mineral-based Industries[1] are shown in Figs. 1 and 2. Based on all these ores and mineral reserves, various industries have been set up in the state. The list of Mineral-based Industries in Odisha (Large and Medium Scale Industries) is shown in Table 1.

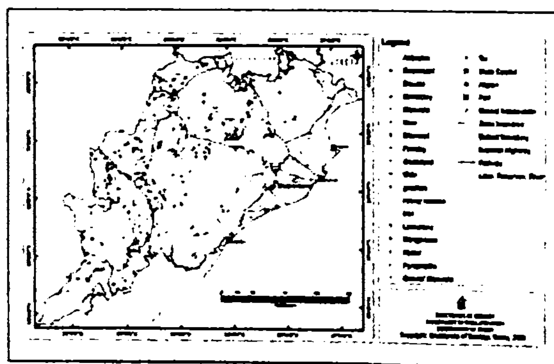


Fig 1: Mineral Map of Odisha (source: Directorate of Mining & Geology, Government of Odisha)

ENVIRONMENT

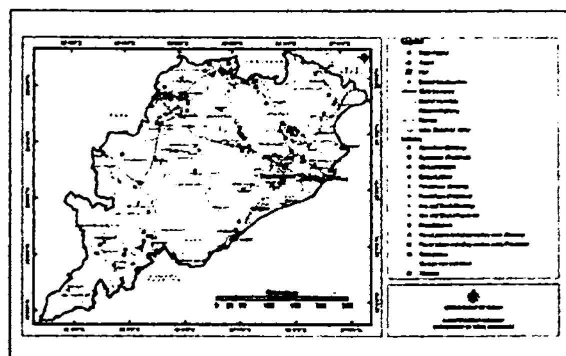


Fig. 2: Mineral-based Industries (source: Directorate of Mining & Geology, Government of Odisha)

Table 1: List of Mineral based Industries in Odisha (Large and Medium Scale Industries)

Name of the Industry	District	Product
Indian Metals and Ferro Alloys Ltd. (CPP Unit), Choudwar	Cuttack	Power
NALCO (CPP), Nalconagar	Angul	Power
Hindalco Industries Ltd., Hirakud	Sambalpur	Aluminium
Hindalco Industries Ltd., PB No.12 Hirakud	Sambalpur	Power
OCL India Ltd. (Cement Unit) Rajgangpur	Sundergarh	Cement
Nava Bharat Ventures Ltd. Kharagprasad, Mermundali	Dhenkanal	Power
Chariot Cement Ltd. (Unit-II) Kalunga Industrial Estate	Sundergarh	Cement
NALCO Smelter, Nalconagar	Angul	Aluminium
IB Thermal Power Station	Sambalpur	Power
UltraTech Cement Ltd., Arda, Jharsuguda	Jharsuguda	Cement
Talcher Thermal Power Station (TIPS) (NTPC), Talcher	Angul	Power
Neelachal Ispat Nigam Ltd., Duburi	Jajpur	Iron & Steel
Visa Steel Ltd., Kalinganagar Industrial Estate	Jajpur	Pig Iron & Lime Coke
Shiva Cement Ltd., Kutra	Sundergarh	Cement
Golchha Pigments Pvt. Ltd. S-3,97 & 98 Kalunga Industrial Estate	Sundergarh	Pigment
Talcher Super Thermal Power Project (NTPC), Kaniha	Angul	Power
Rourkela Steel Plant, Rourkela	Sundergarh	Steel
Bargarh Cement Works (ACC)	Bargarh	Cement
NTPC, SAIL, Power Company Ltd., Rourkela	Sundergarh	Power
Toshali Cements Pvt. Ltd., Ampavalli, Sunki	Koraput	Cement
K.G.N. Cement (P) Ltd., Mandiakudar, P. O. - Kanshabhal	Sundergarh	Cement
Mideast Integrated Steel Ltd. Khurunti, P. O. - Danagadi	Jajpur	Integrated Steel
RSP (CPP), Rourkela	Sundergarh	Power
Sita Cement Ltd. (Sundergarh) Telighana, Kutra	Sundergarh	Cement
Sushila Cement Pvt. Ltd.	Sundergarh	Cement
Jindal Stainless (CPP) Loidapada	Jajpur	Power
Kapilas Cement Works of M/s OCL India Ltd. Biswali, Barunia	Cuttack	Cement
Vedanta Aluminium Ltd. Bhurkhamunda	Jharsuguda	Aluminium & Power
Anuja Ceramics Pvt. Ltd.	Khurda	Ceramic Product
Essar Steel Ltd.	Jajpur	C L O & Ore Fines
FACOR	Bhadrak	Ferro Alloys
Ferro Alloys Plant, TISCO, Bamnipal	Keonjhar	Charge Chrome
Ferro Manganese Plant, TISCO, Joda	Keonjhar	Ferro Alloys
GKW Limited (Powmex Steel Ltd.)	Balangir	Steel & Alloyed Steel
Hiranya Garva China Clay & Mineral (P) Ltd.	Mayurbhanj	Beneficiation (China clay)
Ib Industry Ltd.	Dhenkanal	Coke
IBP Co. Ltd.	Angul	Explosives
IBP Co. Ltd.	Jharsuguda	Explosives
ICCL (CPP)	Cuttack	Ferro Alloys
IFGL Refractory (Unit-I & Unit-II)	Sundergarh	Refractories
IREL (OSCOM)	Ganjam	Synthetic Rutile, Pure Zirconia, Zirflour
IDCOL Ferro Chrome Plant	Jajpur	Ferro Alloys
IDL Industries Ltd.	Sundergarh	Explosives
IMFA (F-1, F-2 & F-3)	Rayagada	Ferro Alloys
Indian Explosives Ltd.	Angul	Explosives
Indian Explosives Ltd.	Sundergarh	Explosives
Indo Gulf Industries Ltd.	Angul	Explosives
IPI Steel Ltd. (F-I & II)	Dhenkanal	Rerolling
Ispat Alloys Ltd. (F-1, F-2, F-3, F-4, F-5)	Baleswar	Ferro Alloys
Shakti Chrome Ltd.	Baleswar	Chrome Briquetting
Jai Mata Ambe Steels Pvt. Ltd.	Sundergarh	Casting
Jeypore Sugar Company Limited (Ferro Mn. Plant)	Rayagada	Ferro Alloys
IDCOL Kalinga Iron Works	Keonjhar	Pig Iron
Konark Met Coke Limited	Cuttack	Coke
Kripal Alloy Steel Private Limited	Bargarh	Auto Components
Kripal Springs (P) Ltd.	Bargarh	Auto Components
Kumar Ceramics Pvt. Ltd.	Baleswar	Refractory Products
Magnetic India Ltd.	Khurda	Hard Ferrite
Mahanadi Metals & Chemicals Pvt. Ltd.	Sundergarh	Explosives
Manishri Refractories & Ceramics Pvt. Ltd.	Cuttack	Refractory Products
NALCO Ltd. (Pilot Plant)	Koraput	Special Grade Aluminium
NALCO Ltd. (Refinery Unit)	Koraput	Aluminium Refinery
NALCO Ltd. (Zeolite)	Koraput	Zeolite
Nava Bharat Ferro Alloys Ltd. (F-I & II)	Dhenkanal	Ferro Alloys
Nilachal Refractories Ltd.	Dhenkanal	Refractory Products
OCL (Refractory Unit)	Sundergarh	Refractory Products
Ordnance Factory	Balangir	Explosives
Orissa Explosives Pvt. Ltd.	Sundergarh	Explosives
Orissa Industries Ltd.	Sundergarh	Refractory Bricks
Orissa Industries Ltd. (Barang)	Cuttack	Refractory Bricks
Padma Engineering Pvt. Ltd.	Jharsuguda	Galvanized Steels
Paradeep Carbon Ltd.	Jagatsinghpur	Petroleum Coke
Passary Minerals Ltd.	Sundergarh	Refractories Raw Material
Pyramid Coke Industries Private Limited	Jajpur	Coke
Refcem Private Limited	Khurda	White Cement

Rourkela Minerals Co. Private Limited	Sundergarh	Bauxite Powder
SLM Metal (P) Ltd	Sundergarh	Copper, Iron & Bronze Powder
Shiva Refractories & Ceramics Ltd	Sundergarh	Refractory Materials
Sri Jagannath Combine Coke	Cuttack	Coke
Sri Mahavir Carbon Limited	Cuttack	Coke
TRL (Refractory Unit)	Jharsuguda	Refractory Products
UAL Industries Ltd	Dhenkanal	Asbestos
Utkal Galvanisers Pvt. Ltd., Kapursingh	Cuttack	Fabrication, Galvanizing
Utkal Graphites (P) Ltd.	Rayagada	Beneficiation of Graphite Ore
Utkal Moulders Ltd.	Keonjhar	Coke
Visa Steel Ltd	Jajpur	Beneficiation Chrome Ore
Wellman Incandescent India Ltd.	Cuttack	Coke

Source: Orissa State Pollution Control Board, Bhubaneswar

Table 2: District wise Distribution of Iron Ore

District	Reserves (in MT)	Grade Range (% Fe)
Sundergarh	742	60-64
Keonjhar and Gandhamardhan	2,555	63-66
Jajpur (Partly Cuttack)	46	63-65
Total	**3,343**	

Main Mineral Resources in Odisha

The main mineral resources of the state consist of the following:

i) Iron Ore
ii) Bauxite
iii) Manganese Ore
iv) Chromite &
v) Coal

Iron Ore

The iron ore deposits of the state occur in four District Geographic Zones namely:

a) Sundargarh
b) Keonjhar/ Gandhamardan
c) Tamka, Daitari—Jajpur/ Cuttack

The district wise distribution of iron ore reserves is given in Table 2.

Bauxite

The bauxite deposits explored by the Directorate of Geology, Govt. of Odisha; GSI, MECL etc. together add up substantially to the total resources of the state, which amounts to 1846 million tonnes of all categories as shown in Table 3.

Table 3: Bauxite Deposits of Odisha

District	Deposits	Reserves (Million Tonnes)				Exploring Agency
		Proved	Probable	Possible	Total	
Koraput	Panchpatmali	314			314	DG & GSI
	Pottangi		76		76	GSI
	Malipartbat		9.8		9.8	GSI
	Ballada		11.5		11.5	GSI
	Kodingamali		81		81	GSI
	Hatimali			3.3	3.3	DG
	Kakrimali			5.2	5.2	DG
	Chintamgundi			12	12	DG
	Kamopodikonda			17	17	GSI
	Nangalmarhimali			3.3	3.3	DG
	Gurji			2.4	2.4	DG
	Medamgundi			5.18	5.18	DG
	Barhaparhu			1.6	1.6	DG
	Phulabandha			2.96	2.96	DG
	Sarbati			0.16	0.16	DG
	Timajhola			0.78	0.78	DG
	Sargighatimali			0.25	0.25	DG
	Nandapur			2.873	2.873	DG
	Khilua			0.84	0.84	DG
	Gerupet			0.77	0.77	DG
	Sagur			0.294	0.294	DG
	Ramgarh				7.47	DG
Rayagada	Majhingamali			19	19	DG
	Indragiri			6	6	DG
	Baphlimali		195		195	GSI
	Sasubohumali-Pasangamali		81		81	DG
	Sijimali		245		245	GSI
	Tikirimali			3.5	3.5	DG
	Budharajamali			3.4	3.4	DG
	Sunderghati			1.6	1.6	DG
	Taljhiri			2.75	2.75	DG
	Narayangundimali			2.77	2.77	DG
	Girimali			0.82	0.82	DG
	Tikiriguda			4.07	4.07	DG
	Dabuguda			1.27	1.27	DG
	Balimala			1.36	1.36	DG
	Kathakhal, Manjimali, Lakhirishi			20	20	DG
	Nunapaimali			6.89	6.89	DG
Malkangiri	Korkanda			9	9	DG
Kalahandi	Karlapat-Pollingpadar	153		54	207	DG
	Kutrumali-Tangridongar			40	40	DG
	Lanjigarh-Niyamgiri		88		88	GSI
	Krishunmali			28	28	DG
	Ketuamali			49	49	DG
Balangir-Bargarh	Gandhamardan		207		207	DG & MECL
Kandhamal	Anamini Parbat			9	9	DG
	Rumkuni Cuttack			3.2	3.2	DG
	Demoli Plateau			21.5	21.5	DG
	Sindhiguda			1.2	1.2	DG
	Ushabali				10.74	
Sundergarh	Tantra, Kusumdihi, Jaldihi, Kamando, Phuljhari			6.3155	6.3155	DG & GSI
	Kodalia		1.97		1.97	
Keonjhar	Dholkatapahar		5	6	11	DG
	Total				**1846.0325**	

Total Bauxite Reserves of Odisha is 1846.0325 Million Tonnes

Manganese Ore

The recoverable reserves of Manganese Ore (25% Mn and above) in India are estimated at about 167 million tonnes. The conditional resources (-25% Mn) are estimated at 2 million tonnes. Odisha with a recoverable reserves of 52.8 million tonnes accounts for 32% of the countries' reserves (Table 4).

Table 4: Reserves of Manganese Ore in Odisha		
Sl. No.	**State**	**Reserves (In MT)**
1.	Bonai-Keonjhar	23.40
2.	Ghoriajhor-Lanigan area, Sundergarh District	Not estimated
3.	Southern and Western Odisha	
	a) Nisikhal-Talodashi block	17
	b) Kutinga-Devjhola	10
	c) Balangir-Kalahandi	Not estimated

On completion of the ongoing exploration program in these three sectors, there is a distinct possibility of the state reserves exceeding 55 million tonnes.

Ferro Manganese Plants

The following Ferro Alloy Plants are operating in the state of Odisha. In the process, they produce various waste materials like Ferro Alloy Slags, accompanied by liquid and gaseous effluents. The name and location of the Plants and their product profiles are furnished in Table 5.

Table 5: Name and Location of the Ferro Manganese Plant and their Product Profiles	
Name & Location of the Plants	**Products**
FACOR, Randia, Bhadrak; (Charge Chrome Division), Randia, Dist. Bhadrak	HC Ferro Chrome/ Charge Chrome
TATA Steel Ltd., Ferro Manganese Plant, Joda, Dist. Keonjhar	HC Ferro Manganese Silico Manganese
TATA Steel Ltd., Ferro Alloys Plant, Bamnipal, Dist. Keonjhar	HC Ferro Chrome Charge Chrome
Balasore Alloy Ltd., Balgopalpur, Dist. Balasore (formerly ISPAT Alloys Ltd.)	Ferro Manganese Silico Manganese Ferro Chrome
Jeypore Sugar Company Ltd., Ferro Manganese Plant, Dist. Rayagada	HC Ferro Chrome Silico Manganese
IDCOL Ferro Chrome and Alloys Ltd., Jajpur Road, Jajpur	LC Ferro Chrome
Indian Charge Chrome Ltd., Choudwar, Cuttack	HC Ferro Chrome Charge Chrome
IMFA, Therubali Rayagada	Ferro Silicon HC Ferro Chrome
Suparv Metals Alloys Pvt. Ltd., Rairangpur, Mayurbhanj	Ferro Columbium Ferro Molybdenum Ferro Tungsten Ferro Vanadium

Chromite

The world resources of chrome ore are 7,500 million tonnes. India with reserves of 186 million tonnes accounts for only 2.5% of world resources. Out of the total geological resources of 186.0 million tonnes in India, Odisha accounts for 182 million tonnes, i.e. 98% and the bulk of it are confined to Sukinda ultramafic belt. The rest 2% is confined to the Baula-Nuasahi complex.

Coal

Occurrence of coal seams has been established along the western fringe and along the northern boundary of Talcher Coalfield. A substantial query able reserves has been located in the northern part of Ib-River Coalfield (Gopalpur area) and towards its southeastern extremity in Khinda-Talabira area. Occurrence of coal seams has also been reported from Raniganj formation of Ib-River Coalfield recently. Table 6 shows the reserves of coal in million tonnes. Thus, the state is not yet saturated with coal discoveries and more new findings cannot be ruled out.

Table 6: Reserves of Coal (in MT)					
Sl. No.	**Reserves**	**Proved**	**Indicated**	**Inferred**	**Total**
1.	Ib-River Coalfield	2225.44	10113.46	9058.04	21396.94
2.	Talcher Sector	5452.17	12654.99	8872.36	2697.52
	Total for Odisha	**7677.61**	**22768.45**	**17930.40**	**48376.46**

The major industrial belt in the states of Odisha (A) Kaniha-Talcher-Angul; (B) Jharsuguda-Brajrajnagar-IB Valley; (C) Kalinganagar-Jajpur Road; (D) NALCO, Damanjodi; (E) Rourkela and (F) Choudwar region produce various industrial wastes like Chemical Slags from Iron & Steel Plants Slag, Fly Ash and Bottom Ash from Thermal Power Plants, Red Mud from Alumina Refinery, Spent Cathode Pot Lining Materials (SPL) from Aluminium Smelter etc., causing environmental hazards. Some of the wastes are designated as hazardous wastes because of their composition and hazardous naturel. There is about 80000 MT/annum of hazardous waste being generated in the state of Odisha. The most polluted belt in Odisha is Talcher and Jharsuguda region as per the report of Orissa State Pollution Control Board. Table 5 presents the installed capacity of different plants in the region. The satellite map of Talcher region clearly shows the loss of green cover and creating an environmental disaster in the region. This has become a pot boil in the country, where temperature goes up to 50°C in the summer, making the life of the people most miserable.

Environmental Management Plan (EMP)

Preparation of environmental management plan is required for formulation, implementation and monitoring of environmental protection measures during and after the commissioning of projects. The plans should indicate the details as to how various measures have been or are proposed to be taken, including cost components as may be required. The cost of measures for environmental safeguards should be treated as an integral component of the project cost and environmental aspects should be taken into account at various stages of the projects:

- Conceptualization: preliminary environmental assessment
- Planning: detailed studies of environmental impacts and design of safeguards

- Execution: implementation of environmental safety measures
- Operation: monitoring of effectiveness of built-in safeguards

The management plans should be necessarily based on considerations of resource conservation and pollution abatement, some of which are:

- Liquid Effluents
- Air Pollution
- Solid Wastes
- Noise and Vibration
- Occupational Safety and Health
- Prevention, Maintenance and Operation of Environmental Control Systems
- Housekeeping
- Human Settlements
- Transport Systems
- Recovery - reuse of waste products
- Vegetal Cover
- Disaster Planning
- Environment Management Cell

Liquid Effluents

- Effluents from the industrial plants should be treated well with the standards as prescribed by the Central/ State Water Pollution Control Boards.
- Soil permeability studies should be made prior to effluents being discharged into holding tanks or impoundments and steps taken to prevent percolation and groundwater contamination.
- Special precautions should be taken regarding flight patterns of birds in the area. Effluents containing toxic compounds, oil and grease have been known to cause extensive death of migratory birds. Location of plants should be prohibited in such type of sensitive areas.
- Deep well burial of toxic effluents should not be resorted so as it can result in re-surfacing and groundwater contamination. Resurfacing has been known to cause extensive damage to crops and livestock.
- In all cases, efforts should be made for reuse of water and its conservation.

Air Pollution

- The emission levels of pollutants from different stacks should conform to the pollution control standards prescribed by the Central or State Board.
- Adequate control equipment should be installed for minimizing the emission of pollutants from various stacks.
- In-plant control measures should be taken to contain the fugitive emissions.
- Infrastructural facilities should be provided for monitoring the stack emissions and measuring the ambient air quality, including micro-meteorological data (wherever required) in the area.
- Proper stack height as prescribed by the Central/State Pollution Control Boards should be provided for better dispersion of pollutants over a wider area to minimize the effect of pollution.
- Community buildings and townships should be built up-wind of the plant with one-half to one-kilometre greenbelt in addition to physiographical barrier.

Solid Wastes

- The site for waste disposal should be checked to verify permeability so that no contaminants percolate into the groundwater or river/lake.
- Waste disposal areas should be planned down-wind of villages and townships.
- Reactive materials should be disposed of by immobilizing the reactive materials with suitable additives.
- The pattern of the filling disposal site should be planned to create better landscape and be approved by the appropriate agency and the appropriately pretreated solid wastes should be disposed, according to the approved plan.
- Intensive programs of tree plantation in the disposal areas should be undertaken.

Noise and Vibration

Adequate measures should be taken for the control of noise and vibrations in the industry.

Occupational Safety and Health

Proper precautionary measures for adopting occupational safety and health standards should be taken.

Prevention, Maintenance and Operation of Environmental Control Systems

- Adequate safety precautions should be taken during preventive maintenance and shutdown of the control systems.
- A system of interlocking with the production equipment should be implemented, where highly toxic compounds are involved.

Housekeeping

Proper housekeeping and cleanliness should be maintained both inside and outside the industry.

Human Settlements

- Residential colonies should be located away from the solid and liquid waste dumping areas. Meteorological and environmental conditions should be studied properly before selecting the site for residential areas in order to avoid air pollution problems.
- Persons who are displaced or have lost agricultural

lands because of locating the industries in the area, should be properly rehabilitated.

Transport Systems

- Proper parking places should be provided for the trucks and other vehicles by industries to avoid any congestion or blocking of roads.
- Location of industries on the highways should be avoided as it may add to more road accidents due to substantial increase in the movements of heavy vehicles and unauthorized shops and settlements coming up around the industrial complex.
- Spillage of chemicals/substances on roads inside the plant may lead to accidents. Proper road safety signs both inside and outside the plant should be displayed for avoiding road accidents.

Recovery - Reuse of Waste Products

Efforts should be made to recycle or recover the waste materials to the extent possible. The treated liquid effluents can be conveniently and safely used for irrigation of lands, plants and fields for growing non-edible crops.

Vegetal Cover

Industries should plant trees and ensure vegetal cover in their premises. This is particularly advisable for those industries having more than 10 acres of land.

Disaster Planning

Proper disaster planning should be done to meet any emergency arising due to fire, explosion, sudden leakage of gas etc. Firefighting equipment and other safety appliances should be kept ready for use during disaster/ emergency, including natural calamities like earthquake/ flood.

Environment Management Cell

Each industry should identify within its setup a Department/Section/Cell with trained personnel to take up the model responsibility of environmental management as required for planning and implementation of the projects.

Environmental Management Practices

Outline

Mining industries perform various activities such as extraction of minerals, processing of minerals and transporting of these minerals to market place. Years of unregulated mining and mineral processing activities like drilling, blasting, crushing and other associated activities have not come without high environmental costs. In comparison with other sectors, the potential social and environmental issues associated with mining and mineral processing operations are both significant and complex to manage. The discovery, extraction and processing of mineral resources is widely regarded as one of the most environmentally and socially disruptive activities undertaken by business[3]. As it is associated with low investment capacity and poor working conditions, which enforces the use of traditional technologies and unskilled manpower, which ultimately negatively affects productivity and maintenance of equipment[4]. This results in the consumption of more energy and the generation of more waste, making it most polluting sector. The negative impact of mining on health, land, water, air, plants and animals, and other aspects of society can be reduced by careful planning and implementation of mining activities. It is essential to strike a balance between mineral developments on one hand and the restoration of the environment on the other.

Mining Scenario in India

Minerals are the basic raw materials, which contribute to the growth of both industrialized and industrializing countries; judicious utilization of mineral resources promotes the economic development of a nation and its people. India is rich with various mineral recourses, which include fossil fuels, ferrous and non-ferrous ores and industrial minerals. Globally, India ranks among the top five players in terms of production of several important minerals. Since 1947, India's mining industry has shown rapid growth. In the pre-plan period prior to 1950, India produced 24 types of minerals with a total value of US$23 million[5]. Today, it produces 90 minerals, with a projected total value to touch over $30 billion (about Rs. 1,27, 662 crore), accounting for about 2.5% of the GDP in the next four years[6]. Public sector mines comprise 91% of the nation's total mineral value, even though 80% of mines are privately owned. By 1996-97, India had 3,488 mines. Of these, 563 were coal, 654 were metals and 2,271 were non-metals[5]. The growth in Indian mining industries due to suitable policy and investment climate supported by favourable market demand has intensified the adverse impact on the environment.

Technical Barriers

Many mines and mineral-based industries in India are either not aware of the current version of technologies or fail to identify the areas, where these advanced technologies could be utilized. In the event that possibilities for the advanced technologies have been identified, at some of the mines, shortage of expertise is experienced. Unfortunately, international standards, which are designed generically and hence, only provide general guidance, lend little in the way of methods to implement practical industry-specific environmental management practices[7]. Fixed location of the mineralized zone of interest imposes a constraint on all aspects of mining development, including the method of mining, the requirement for new infrastructure and services, and the suitability of waste management or, disposal methods[8].

Mining and mineral-based industries in India have their own setup of technologies, mostly imported, which provides guidelines for operation of mining and the related

industrial enterprise. The technology suppliers provide the complete technology package with operating guidelines for day-to-day mining and production. Engineering consultancy firms have provided required engineering backup for the same. Furthermore, Continued Technical Assistance (CTA) is also provided by the technology suppliers. Equipment and Machinery suppliers do also provide operations and instruction manual for safe operation of mining and plant equipment. Operating Personnel also undergo technical trainings for smooth operation of plant and machineries. Safety, health and environmental issues are given due importance during the course of the entire operation process.

However, in spite of all these measures, technical barriers do exist and all necessary steps should be taken to effectively address the environmental management issues to maintain healthy management practices.

Lack of Management Commitment

Top management in most of the mining companies is less concerned over environmental issues and reluctant to allocate adequate financial, technological and human resources to implement the green management practices. There is also an inevitable amount of hesitancy by top management towards implementation of green management practices as it involves huge amount of documentation work and a serious non-compliance uncovered during the environmental auditing process might lead to social outcry or, even legal action[9].

Lack of Employee Commitment

Mining companies do not have a proper performance evaluation system; they also do not have a proper rewarding scheme for the employees to motivate them to be held responsible for protecting the environment. The roles, responsibilities and authority of the staff are neither properly defined nor communicated to all organizational members. This leads to confusion among staffs regarding their responsibilities and poor motivation towards environmental protection practices.

Lack of Awareness

Poor awareness regarding environment among politicians, citizens, and bureaucracy is compounded by low levels of literacy and the poor mass media concern[10]. Regulators at all levels are severely limited by lack of adequate & useable information as also clarity and definition on several aspects pertaining to mining operations. This creates necessary gaps for illegal operations to function and flourish unchecked[8]. Another serious problem in this regard is the veil of secrecy maintained by the Government Department and the general non-availability of information on environmentally sensitive issues[11]. Workers and trade union leaders are generally not aware of occupational health problems. Managements also are unaware of opportunities for cost savings in the areas of waste reduction or elimination of pollution, energy-efficiency and prevention & mitigation of accidents.

Inappropriate Approach to Implementation

Many enterprises mistakenly begin implementation immediately, following an initial environmental diagnosis without critically reviewing objectives and policies[12]. Top management often ignores refining pertinent environmental objectives and actions, and conduction of multiple environmental reviews before implementing the environmental management practices. Indian mining sectors lack effective monitoring system, whose primary purpose is to assess the mine's actual environmental performance against the stated environmental policies, objectives and targets. Administrative delays, apathy and inadequate personnel training and lack of interdepartmental coordination during implementation prevent environmental protection and improvement. Short-term focus is another contributing factor in failing to achieve the desired environmental culture[9].

Suggested Road Map

Some of these challenges for implementation of green management practices in Indian mining industries have been suggested. Identification of potential barriers can help a manager develop strategies to minimize the impact of those barriers. At present, mines in India confronted by these barriers remain heavy polluters, or, at best, stagnant in terms of environmental performance. Regional Government must play an expanded role in disseminating valuable information and technology to mines. The government has also an important role to play in providing training opportunities and in ensuring that safety and health regulations are appropriate and are observed.

R&D Efforts for Waste Utilization

R&D efforts for waste utilization is a major challenge for the scientific communities, particularly in the ferrous and non-ferrous sectors, pertaining to iron ore, bauxite, manganese ore, chromite and coal. The present paper describes only on R&D efforts undertaken for the utilization of solid wastes.

R&D Efforts in Iron Ore Sector

Solid waste materials generated in iron ore sector generally are iron ore fines, slimes, blue dust, blast furnace slags, steel mill slags, mill scales etc., in addition to gaseous and liquid effluents.

Efforts have been made to produce value-added materials from iron ore fines and slimes through pyro-metallurgical route for production of sinters, Direct Reduced Iron (DRI), and metallic iron. All these products have been properly characterized and their industrial applications have been established. Novel innovative

practices have also been employed for the production of Green Steel from iron ore fines by application of Hydrogen Plasma Smelting Reduction process, thereby developing an eco-friendly process for steelmaking contrary to the conventional Blast Furnace route. In this process, water is generated as by-products, which can be utilized in the commercial plant.

R&D Efforts in Bauxite -Alumina-Aluminium Sector

Alumina is produced from bauxite, utilizing the time tested Bayer's process. It has been estimated that from 3 tonnes of bauxite, 2.0 tonnes of Red Mud and 01 tonne of alumina are produced. Bauxite is digested with caustic soda and alumina present in bauxite goes into solution producing sodium aluminate liquor and the residual metal oxides predominately dominated by ferric hydroxide gets precipitated as Red Mud, which is pumped in the slurry for into the nearby pond. Red Mud, being caustic in nature, has been termed as a hazardous waste material and is to be handled with due care and precautions.

R&D efforts have been made for the production of different value-added items from Red Mud such as Recovery of Iron from Red Mud; Red Mud Bricks, Blocks and Tiles; Red Mud Fibre Reinforced Polymer composite for building components as wood substitute; Red Mud Cement; Red Mud as soil amending agents; Red Mud Paints and Pigments; Red Mud -Fly Ash, Bricks, Blocks and Tile; Green Steel from Red Mud by application of Hydrogen Plasma Smelting Reduction Technology etc. Necessary process knowhow/ technology is available for commercial exploitation.

In the aluminium smelter. Spent Cathode Pot Lining Material (SPL) is generated, which is considered as a hazardous waste material in aluminium industries. SPL contains fluorides and cyanides and is properly stored in the plant premises with due care and as per the guidelines of Pollution Control Board. R&D efforts have been made for utilization of SPL in cement-making. Lot more efforts need to be undertaken for its bulk utilization.

R&D Efforts in Manganese Ore Sector

During the mining of Manganese Ore, Manganese Ore fines are produced containing a good amount of manganese and needs to be exploited for the production of value-added items. R&D efforts have been made for the production of manganese sinters from manganese ore fines, which is then used in Submerged Arc Smelting Furnace for the production of Ferro Manganese. Ferro Manganese is utilized for the production of special manganese steel.

R&D Efforts in Chromite Sector

Odisha is endowed with rich chromite reserves, particularly in the Sukinda region of Jajpur district. During mining of one tonne of Chrome Ore, 6-7 tonnes of Chromite Over Burden (COB) are generated, which stock piled in the mining area containing a good amount of nickel from 0.3 to 0.9%, according to the depth of the mining. R&D efforts have been made to process this COB for the production of pure Nickel by application of Reduction Roasting, followed by an Ammonical Leaching process. Efforts have also been made for the production of nickel bearing pig iron by sintering and smelting process and Ferro Nickel by Reduction Roasting, followed by Magnetic Separation and Smelting Process.

R&D Efforts in Coal Sector

Coal reserves of Odisha contain high ash content, which needs to be beneficiated prior to its use in metallurgical applications. R&D efforts have been made in this direction and coal of high ash content have been beneficiated successfully to reduce it from 38 to 13%. This low ash content coal is utilized in coke-making for metallurgical application.

The coal of high ash content, used in Thermal Power Plants, generates huge quantities of fly ash, which is considered as an industrial menace. R&D efforts have been made in the bulk utilization of fly ash and results in this direction have been very promising. Fly ash bricks and blocks, fly ash cements, fly ash-red mud bricks and blocks etc. have been successfully made in large quantities under a pilot scale and state-of the-art technology have been developed for commercial utilization.

Fly ash finds large scale applications in road making, back mine filling, cement manufacturing and other such construction sector successfully. However, further efforts are required at national level to enhance the percentage of utilization to match international scale.

Future Prospects

The future prospects of waste utilization lie with the development of new technologies and its scale of operation for bulk utilization. Furthermore, techno-economic feasibility of the process know-how is to be established and societal acceptability of the product is most essential. A strong synergy amongst Technology Developers, Industrial Houses, Entrepreneurs, Academia, Research Institutes, Government Agencies and Society is the key factor for the successful utilization of wastes. The strategy should be "Waste to Wealth" and technology should play an important role in this endeavour so that national goal is achieved for all-round growth and economic prosperity of the country.

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CHAPATER 2

Importance of Establishment of Technology Development Center

Keywords: Industrial and Mineral Wastes, Semi-commercial Scale Units Value-added Items

Promotion of Semi-Commercial Units for Utilisation of Industrial & Mineral Wastes for Production of Value-added Items under the Umbrella of Technology Development Centre





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The state, Odisha, is rich with mineral resources along with a long stretch of coastal line covering a distance of around 450 km. Further, it is backed by rich cultural heritage over and above one of the best natural resources, forest ecosystem and water resources, etc. The state is also endowed with vast coal reserves for production of thermal power in addition to hydroelectric power for catering to the energy requirement of the state. The academic and research climate of the state is one of the best in the country, attracting talented human resources from all over the country for building up their career in the state. The state capital Bhubaneswar is now termed as the Academic and Research capital of the country. The state has 22 Universities backed by around 100 Engineering and Technological Colleges in addition to IIT, IIM, IISER, NISER, Central University, etc. Moreover, during the last one decade or so, the state has witnessed progressive development in all spheres of economy be it Hotel Industry, IT Industry, MSME (Medium and Small Scale Enterprises) Sectors, Communication Technology, Infrastructure Development, Airways, Roadways, Railways and Waterways, etc. The industrial landscape of the state is changing and is changing at a faster pace adding substantially to the Gross Domestic Product (GDP) of the nation. In spite of all such valuable assets, Odisha still continues to be one of the poorest states of the nation ranking 3rd in seriatim.

The various waste materials and by-products, generated by the industries of the state are required to be used for production of different value-added items. Furthermore, wastes generated from mining and mineral activities are also to be properly tapped for the said purpose. Presently, research activities in industries, academia and research institutes in this direction are confined primarily into laboratory/pilot scale research and there is an urgent need to scale up the operation into semi-commercial scale. This can be realised by setting up of a "Technology Development Centre" in the state where the successful laboratory/pilot scale projects can be scaled up to semi-commercial scales. The present paper describes the importance of promoting the development of semi-commercial units for utilisation of industrial and mining wastes for production of value-added items under the umbrella of "Technology Development Centre".

Introduction

Today's fast-paced world envisages 'Technology' as the most basic tool of any industry, and it should be techno-commercially feasible and economically viable. Then and then only, an industry will be sustainable and it will grow at par with the growth of national GDP. However, industrial units operating either in the state or in the country are primarily depending on import of technology at an exorbitant cost and continue to depend on the same during the project implementation operation

maintenance, modernisation, expansion and diversification stages, etc thereby siphoning out huge amount of money to the foreign exchequer Industries depend mainly on import of technology and Continued Technical Assistance (CTA) is rendered by the technology supplier till the lifespan of the project. This trend is required to be reversed and that is only possible through dependence on indigenous technology and application of the same for setting up industrial enterprises. For this to happen, dedicated Scientific and Technological Collaborations is a must amongst the Academia, Research Institutes and Industrial Houses. But, the problem lies with the fact that industries do not trust our scientific manpower and they have a typical mindset of depending on import of technology over the years. They are also correct because the National Laboratories and Academia, which are considered as the Technology Bank of the Nation, are unable to provide a Proven Technology and a Full Proof Technology Package to the industries so that they can go ahead for setting up commercial entities. What they provide is at best a Laboratory/ Pilot Scale Technology based on which industries are unable to take Investment Decisions for setting up commercial ventures. So, there is a need to scale up the technology from the Laboratory / Pilot Scale to Semi-Commercial Scale and develop a Complete Technology Package and prepare a Techno-Economic Feasibility Report (TEFR) and Basic Engineering, so that industries will come forward to join hands with the Academia and Research Institutes to avail the golden domestic opportunity for realisation of their industrial dreams.

The relevance of "Promoting the Development of Semi-Commercial Units for Utilisation of Industrial & Mineral Wastes for Production of Value-added Items under the Umbrella of Technology Development Centre" is more pronounced these days towards the industrialisation of Odisha. No doubt, our state is endowed with rich mineral resources and has got a long coastal line with diversified ecosystem. But for promotion of development of semi-commercial units for production of value-added items from industrial & mineral wastes needs planned and sustained growth of infrastructure, i.e. railway and road connectivity, water and power supply arrangement and port facility, etc. in addition to strong S&T collaborations amongst Academia, Research Institutes and Industries.

At present, we are deprived of such Semi-Commercial Units where the Laboratory/Pilot Scale Technology can be repeatedly tried out till the technology is proven and acceptable to industrial houses for commercialisation of process know-how. Such Semi-Commercial Units can be set up in a Technology Park, which can be designated as "Technology Development Centre". This centre can house many semi-commercial units for utilisation of industrial and mineral wastes for production of different value-added items. Furthermore, a Marketing Cell is required to be set up in the centre to undertake Market Survey of such value-added items, so that these value-added items can penetrate into the market economy in their bulk consumption both in the country and abroad. The Technology Development Centre will develop technology, market technology, develop value-added products from industrial and mineral waste and market the same domestically and globally.

Location of Technology Development Centre

There are three options available before us to locate Technology Development Centre in the state. The centre can be set up either in the premises of Academic Institutions, Research Organisations and Industrial Houses.

Academic Institutions

The Academic Institutions are busy in their day to day classroom teachings, examinations, sports & cultural activities, NCC, NSS, College Union activities, Excursions, Industrial Tour, Convocations, Seminar & Symposiums and M. Phil. and PhD Research programs, etc. They are hard pressed to achieve academic excellence and have practically no time to devote to the Technology Development Centre.

Research Organisations

The second option lies with the Research Organisations working in the state of Odisha. Of late, many National S&T Institutes are operating in the state of Odisha and they are engaged in the various fields of R&D activities to achieve the national goal. They are mainly engaged in development of Minerals and Materials Technology, Life Sciences, Medial Research, Agricultural Research, Bio Technology, Nano-Technology, Information Technology, Plastic Engineering and Technology, Material Sciences, Geo Sciences and Technology, Earth Science and Technology, Earth Atmospheric and Oceanography, Disaster Management, Weather Science and Meteorology, Physical Sciences and Technology, Fishery, etc. They have their respective research plans and programs and are engaged in development of new technologies. They have their own scheme of things and also have their own limitations and constraints, be it financial, infrastructural, technical manpower or other associated issues. Moreover, intra-institutional linkages and linkages with industrial houses and academia are also limited. So, the possibility of setting up of semi-commercial units within the institutional framework seems to be foggy and may not be so feasible.

Industrial Houses

From the above two alternative concepts, it may be evident that setting up of semi-commercial units from industrial and mineral wastes for production of value-added items either in the premises of Academic Institutions and Research Organisation may not be feasible from a practical point of view. As a result, the responsibility lies with the Industrial Enterprises and they should come forward to shoulder this important national responsibility. Industrial houses have their own commercial production facilities backed by sound infrastructural facilities, required manpower base, water and energy resources, raw materials, etc. to support for setting up of such semi-commercial units for production of different value-added items from industrial wastes. Each and every industry can have their own semi-commercial production facilities to treat the waste materials generated by them for production of different value-added items. Furthermore, industrial houses have their marketing network both in the country and abroad for marketing the value-added

product in a cost-competitive manner. So, the proposition of setting up of semi-commercial units for production of different value-added items from industrial and mineral wastes in the premises of respective industrial entities may be rightly justified, looks more reasonable and attractive. These semi-commercial production units can function under the umbrella of "Technology Development Centre" with strong collaborations with different Academia and Research Organisations.

Industrial and Mineral Wastes Generated in Odisha

Odisha is a mineral-rich state that has huge deposits of Iron Ore predominantly in the tribal regions of the state. Besides iron ore (more than 35% of the country's iron ore reserves with 5231 million tonnes of iron ore), it counts for 26% Coal and 67.6% Manganese reserves of the country. About 98% of the total proved Chromite (Chromium ore) reserves of the country, of which about 97% occur in the Sukinda Valley covering approximately 200 sq. km in the Jajpur district, is used for production of Iron-Chromium alloys (Ferro-chrome). The state has world's 4th largest bauxite reserves with a total deposit of 1805 million tonnes constituting about 58% of the country's total reserves of the ore that is used to make Aluminium. The Mineral Map of Odisha and Mineral based Industries is shown in Fig. 1 and Fig. 2. Based on all these ores and mineral reserves, various industries have been set up in the state. The list of Mineral-based Industries in Odisha (Large and Medium Scale Industries) is shown in Table 1.

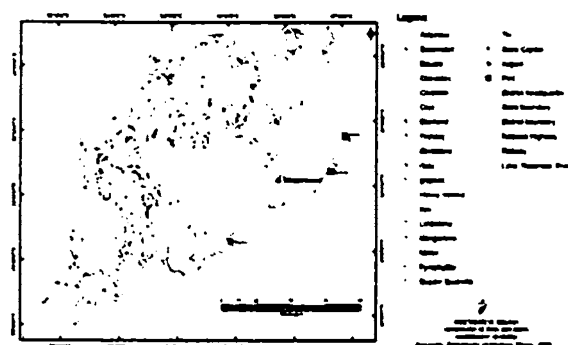


Fig. 1: Mineral [illegible] Odisha [illegible] Government of Odisha

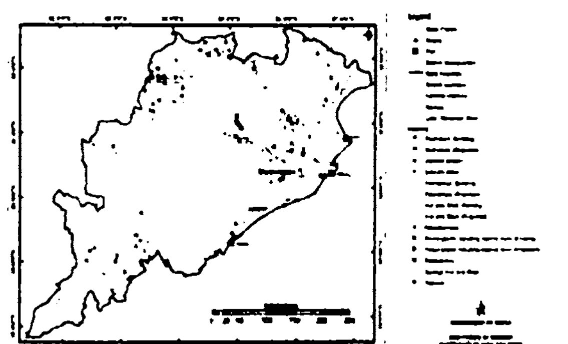


Fig. 2: [illegible] Geology, Government of Odisha

Main Mineral Resources in Odisha

The main mineral resources of the state consist of the following:

i) Iron Ore

ii) Bauxite

iii) Manganese ore

iv) Chromite &

v) Coal

Iron Ore:

The iron ore deposits of the state occur in four District Geographic Zones namely:

a) Sundargarh

b) Keonjhar/Gandhamardan

c) Tamka, Daitari—Jajpur/Cuttack

The district wise distribution of iron ore reserves is given in Table 2.

Table 1: List of Mineral based Industries in Odisha (Large and Medium Scale Industries)

Name of the Industry	District	Product
Indian Metals and Ferro Alloys Ltd (CPP Unit), Choudwar	Cuttack	Power
NALCO (CPP) Nalconagar	Angul	Power
Hindalco Industries Ltd., Hirakud	Sambalpur	Aluminium
Hindalco Industries Ltd., P.B. no. 12, Hirakud	Sambalpur	Power
OCL India Ltd. (Cement Unit), Rajgangpur	Sundargarh	Cement
Nava Bharat Ventures Ltd., Kharagprasad, Meramundali	Dhenkanal	Power
Chariot Cement Ltd. Unit II, Industrial Estate, Kalunga	Sundargarh	Cement
NALCO Smelter, Nalconagar	Angul	Aluminium
IB Thermal Power Station	Sambalpur	Power
Ultratech Cement Arda, Jharsuguda	Jharsuguda	Cement
Thalcher Thermal Power Station (TTPS) (NTPC), Talcher	Angul	Power
Nilachal Ispat Nigam Ltd., Duburi	Jajpur	Iron & Steel
Visa Steel Ltd., Kalinganagar Industrial Estate	Jajpur	Pig Iron & Lime Coke
Shiva Cement Ltd., Kutra	Sundargarh	Cement
Golcha Pigment (P) Ltd., [illegible] Kalunga Industrial Estate	Sundargarh	Pigment
Thalcher Super Thermal Power Project (NTPC), Kaniha	Angul	Power
Rourkela Steel Plant, Rourkela	Sundargarh	Steel
Baragada Cement Works (ACC)	Baragada	Cement
NTPC SAIL Power Company Ltd, Rourkela	Sundargarh	Power
Toshali Cement (P) Ltd., Ampavalli, Sunki	Koraput	Cement
K.G.N. Cement (P) Ltd, Mandiakudar, P.O. Kansbahal	Sundargarh	Cement
Meadcast Integrated Steel [illegible] Khurunti, Danagadi	Jajpur	Integrated Steel

RSP (CPP), Rourkela	Sundargarh	Power
Sita Cement (Sundargarh), Telighana, Kutra	Sundargarh	Cement
Sushila Lenient (P) Ltd.	Sundargarh	Cement
Jindal Stainless (CPP), Loidapacia	Jajpur	Power
Kapilash Cement Works of M/s OCL India Ltd., Biswali, Barunia	Cuttack	Cement
Vedanta Aluminium Ltd., Bhurkhamunda	Jharsugada	Aluminium & Power
Annuja Ceramics	Khurda	Ceramic Product
Essar Steel	Jajpur	CLO & Ore Fines
FACOR	Bhadrak	Ferro Alloys
Ferro Alloys Plant, TISCO, Bamnipal	Keonjhar	Charge Chrome
Ferro Manganese Plant, TISCO, Joda	Keonjhar	Ferro Alloys
G. K W Ltd. (Povimex Steel Ltd.)	Balangir	Steel & Alloyed Steel
Hiranya Garva China Clay & Mineral (P) Ltd.	Mayurbhanj	Beneficiation (China clay)
I. B. Industry Ltd.	Dhenkanal	Coke
I. B. P. Co. Ltd.	Angul	Explosive
I. B P. Co. Ltd.	Jharsuguda	Explosive
I. C. C. L (CPP)	Cuttack	Ferro Alloys
IFGL Refractory (Unit-I & Unit-II)	Sundargarh	Refractories
I. R. E (OSCOM)	Ganjam	Synthetic Rutile, Pure Zirconia, Zifflour
IDCOL Ferro Chrome Plant	Jajpur	Ferro Alloys
IDL Industries Ltd.	Sundargarh	Explosive
IMFA (F-1, F-2 & F-3)	Rayagada Ferro	Alloys
Indian Explosive Ltd.	Angul	Explosive
Indian Explosive Ltd.	Sundargarh	Explosive
Indo Gulf Industries Ltd.	Angul	Explosive
IPI Steel Ltd. (F-I & II)	Dhenkanal	Rerolling
Ispat Alloys Ltd.- F-1, F-2, F-3, F-4, F-5	Baleswar	Ferro Alloys
Ispat Chrome Ltd.	Baleswar	Chrome Briquetting
Jaimata Ambe Steels (P) Ltd.	Sundargarh	Casting
Jeypore Sugar Company Ltd. (Ferro Mn. Plant)	Rayagada	Ferro Alloys
Kalinga Iron Works, Keonjhar Pig Iron, Konark Met Coke Ltd.	Cuttack	Coke
Kripal Alloys Steel (P) Ltd.	Baragada	Auto Components
Kripal Spring (P) Ltd.	Baragada	Auto components
Kumar Ceramics (P) Ltd.	Baleswar	Refractory Products
Magentic India Ltd.	Khurda	Hard Ferrite
Mahanadi Metals & Chemicals (P) Ltd.	Sundargarh	Explosive
Mansri Refractories & Ceramics	Cuttack	Refractory Products
NALCO Ltd., (Pilot Plant)	Koraput	Special Grade Aluminium
NALCO Ltd., (Refinery Unit)	Koraput	Aluminium Refinery
NALCO Ltd., (Zeolite)	Koraput	Zeolite
Nave Bharat Ferro Alloys Ltd., (F- I & II)	Dhenkanal	Ferro Alloys
Nilachal Refractories Ltd.	Dhenkanal	Refractory Products
OCL (Refractory Unit)	Sundargarh	Refractory Products
Ordnance Factory	Bolangir	Explosive
Orissa Explosives (P) Ltd.	Sundargarh	Explosive
Orissa Industries Ltd.	Sundargarh	Refractory Bricks
Orissa Industry Ltd., (Barang)	Cuttack	Refractory Bricks
Padma Engineers (P) Ltd.	Jharsuguda	Galvanized Steels
Paradeep Carbons Ltd.	Jagatsinghpur	Petroleum Coke
Pasary Minerals Ltd.	Sundargarh	Refractories Raw Material
Pyramid Coke Industries (P) Ltd.	Jajpur	Coke
Refcem Pvt. Ltd.	Khurda	White Cement
Rourkela Minerals Company (P) Ltd.	Sundargarh	Bauxite Powder
S. L. M. Metals	Sundargarh	Copper, Iron & Bronze Powder
Shiva Refractories & Ceramics Ltd.	Sundargarh	Refractory materials
Sri Jagannath Combine Coke	Cuttack	Coke
Sri Mahavir Carbon Ltd.	Cuttack	Coke
TRL (Refractory Unit)	Jharsuguda	Refractory products
Utkal Asbestos Ltd.	Dhenkanal	Asbestos
Utkal Galvanisers (P) Ltd., Kapursingh	Cuttack	Fabrication, Galvanizing
Utkal Graphites (P) Ltd.	Rayagada	Benification of Graphite Ore
Utkal Mounders Ltd.	Keonjhar	Coke
Visa Industries Ltd.	Jajpur	Benification Chrome Ore
Wellman Incandescent India Ltd.	Cuttack	Coke

Source: Orissa State Pollution Control Board, Bhubaneswar

Table 2: District wise Distribution of Iron Ore

District	Reserves (in MT)	Grade Range (% Fe)
Sundargarh	742	60-64
Keonjhar and Gandhamardhan	2,555	63-66
Jajpur (Partly Cuttack)	46	63-65
Total	3, 343	

Bauxite Ore

The deposits of Bauxite are explored by the Directorate of Geology, Govt. Odisha; GSI, MECL, etc., together add up substantially to the total resources of the state, which amounts to 1846 Million Tonnes of all categories as shown in Table 3.

Table 3: Bauxite Deposits of Odisha

District	Deposits	Reserve (Million Tonnes)				Exploring Agency
		Proved	Probable	Possible	Total	
Koraput	Panchpatmali	314			314	DG & GSI
	Pottangi		76		76	GSI
	Maliparbat		9.8		9.8	GSI
	Ballada		11.5		11.5	GSI
	Kodiangamali		81		81	GSI
	Hatimali			3.3	3.3	DG
	Kakrimali			5.2	5.2	DG
	Chintamgundi			12	12	DG
	Karnapodikonda			17	17	GSI
	Nangalmarhimali			3.3	3.3	DG
	Gurji			2.4	2.4	DG
	Medamqundi			5.18	5.18	DG
	Barhaparhu			1.6	1.6	DG
	Phulabandha			2.96	2.96	DG
	Sarbeti			0.16	0.16	DG
	Timajhola			0.78	0.78	DG
	Sagrgighatimali			0.25	0.25	DG
	Nandapur			2.873	2.873	DG

Continue..

Raygada	Khilua			0.84	0.84	DG
	Gerupet			0.77	0.77	DG
	Sagur			0.294	0.294	DG
	Ramgarh				7.47	DG
	Manjhingamali			19	19	DG
	Indragiri			6	6	DG
	Baphilimali		195		195	GSI
	Sasubohumali-Pasangamali		81		81	DG
	Sijimali		245		245	GSI
	Tikirimali			3.5	3.5	DG
	Budharajamali			3.4	3.4	DG
	Sunderaghati			1.6	1.6	DG
	Taljhiri			2.75	2.75	DG
	Narayangudamali			2.77	2.77	DG
	Girimali			0.82	0.82	DG
	Tikiiguda			4.07	4.07	DG
	Dabuguda			1.27	1.27	DG
	Balimala			1.36	1.36	DG
	Kathakhal, Manjimali, Lakhirishi			20	20	DG
	Nunapaimali			6.89	6.89	DG
Malkangiri	Korkanda			9	9	DG
Kalahandi	Karlapat-Pollingpadar	153		54	207*	DG
	Kutrumali-Tangridongar			40	40	DG
	Lanjigarh-Niyangiri		88		88	GSI
	Krishunmali			28	28	DG
	Keluamali			49	49	DG
Bolangir-Bargarh	Gandhamardan		207		207	DG & MECL
Kandhamal	Anaminiparbat			9	9	DG
	Rukunicuttack			3.2	3.2	DG
	Dimoliplateau			21.5	21.5	DG
	Sindhiguda			1.2	1.2	DG
	Ushabali				10.74	
Sundergarh	Tantra, Kusumdihi, Jaldihi, Kamando, Phuljhari			6.3155	6.3155	DG & GSI
	Kodalia		1.97		1.97	
Keonjhar	Dholkatapahar		5	6	11	DG
	Total				1846.0325	

Total Bauxite Reserves of Odisha is 1846.0325 Million tonnes

Manganese Ore

The recoverable reserves of Manganese Ore (25% Mn and above) in India are estimated at about 167 million tonnes. The

Table 4: Reserves of Manganese Ore in Odisha

Sl. No	State	Reserve (in MT)
1.	Bonai- Keonjhar	23.40
2.	Ghorlajhor- Laingan area, Sundargarh District	Not estimated
3.	South and Western Odisha	
	a) Nisikhal- Talodashi block	17
	b) Kuttinga- Devjhola	10
	c) Bolangir- Kalahandi	Not estimated

conditional resources (-25% Mn) are estimated at 2 million tonnes. Odisha with a recoverable reserve of 52.8 million tonnes accounts for 32% of the countries reserve (Table-4).

On completion of the ongoing exploration program in these three sectors, there is a distinct possibility of the state reserves exceeding 55 million tonnes.

Ferro-Manganese Plants

Below mentioned is the list of different Ferro-Alloy plants operating in the state of Odisha. In the process, they produce various waste materials like Ferro-Alloys Slags, accompanied by liquid and gaseous effluents. The name and location of the plants and their product profile is furnished in Table 5.

[illegible]

Name & Location of the Plants	Products
FACOR, Randia, Bhadrak (Charge-Chrome Division), Randia, Dist. Bhadrak	HC Ferro-Chrome/ Charge-Chrome
TATA Steel Ltd., Ferro-Manganese Plant, Joda, Dist. Keonjhar	HC Ferro-Manganese Silico-Manganese
TATA Steel Ltd., Ferro-Alloy Plant, Bamnipal, Dist. Keonjhar	HC Ferro-Chrome Charge-Chrome
Balasore Alloy Ltd., Balgopalpur Dist. Balasore (Formerly ISPAT Alloys Ltd.)	Ferro-Manganese Silico-Manganese Ferro-Chrome
Jeypore Sugar Company Ltd. (Ferro-Manganese Plant), Dist. Rayagada	HC Ferro-Chrome Silico-Manganese
IDCOL Ferro-Chrome and Alloys Ltd., Jajpur Road, Jajpur	LC Ferro-Chrome
Indian Charge Chrome Ltd., Chaudwar, Cuttack	HC Ferro-Chrome Charge-Chrome
IMFA, Therubali, Raygada	Ferro-Silicon HC Ferro-Chrome
Suparv Metals Alloys Pvt. Ltd., Rairangpur, Mayurbhanj	Ferro-Columbium Ferro-Molybdenum Ferro-Tungsten Ferro-Vanadium

Chromite

The Chrome Ore deposits account for 7,500 million tonnes in the entire world. India, with a reserve of 186 million tonnes, accounts for only 2.5% of world resources. Out of the total geological resources of 186.0 million tonnes in India, Odisha accounts for 182 million tonnes, i.e. 98% and the bulk of it is confined to Sukinda ultramafic belt. The rest 2% is confined to the Boula-Nuasahi complex.

Coal

The Coal reserves of the state have been established along the western fringe and also along the northern boundary of Talcher Coalfield. A substantial reserve has been located in the northern part of Ib-River Coalfield (Gopalpur area) and towards its southeastern extremity in Khinda-Talabira area. Occurrence of coal seams has also been reported from Raniganj formation of Ib-River Coalfield recently. Table 6 shows the reserve of coal in million tonnes. Thus, the state is not yet saturated with coal discoveries and many more new findings cannot be ruled out.

[illegible]					
Sl. No	Reserve	Proved	Indicated	Inferred	Total
1.	Ib-River Coalfield	2225.44	10113.46	9058.04	21396.94
2.	Talcher Sector	5452.17	12654.99	8872.36	2697.52
	Total for Odisha	7677.61	22768.45	17930.40	48376.46

The significant industrial belts in the state of Odisha are: (A) Kanhia-Talcher-Angul; (B) Jharsuguda- Brajrajnagar-IB Valley; (C) Kalinganagar-Jajpur Road; (D) NALCO, Damanjodi (E) Rourkela and (F) Choudwar Region produce various industrial wastes like Chemical Slags from Iron & Steel Plants Slag, Fly Ash and Bottom Ash from Thermal Power Plants, Red Mud from Alumina Refinery, Spent Cathode Pot Lining Materials (SPL) from Aluminium Smelter, etc. causing environmental hazards. Some of the wastes are designated as hazardous wastes because of their composition and natural hazards. There is about 80000 Mt/annum of hazardous waste being generated in the state of Odisha. The most polluted belt in Odisha is Talcher and Jharsuguda region as per the report of Orissa State Pollution Control Board. Table 5 presents the installed capacity of different plants in the region. The satellite map of Talcher region clearly shows the loss of green cover and creating an environmental disaster in the region. This has become a pot boil in the country where temperature goes up to 50°C in the summer, making the life of the people most miserable.

R&D Efforts made towards Utilisation of Industrial & Mineral Wastes for Production of different value -added items

So far, we have discussed about the production of various Industrial and Mineral wastes generated by different industrial sectors in the state. It is now pertinent to focus our attention for bulk utilisation of such industrial wastes for production of different value-added items through setting up of Semi-Commercial Entities preferably within the premises of different industries following the laboratory/Pilot Scale pathways. Researchers working in Academia, Research Institutes and Industrial Houses undertake their own R&D activities in this area. Major achievements in this direction can be described as follows:

Iron and Steel Sectors

The existing route of producing iron in Blast Furnace is accompanied by environmental hazards for which researchers are on their toes to come up with an eco-friendly alternative. Blast Furnace route produces slags associated with emission of gaseous effluents. From these slags, Slag Cements have been prepared, which have been accepted for use in construction and allied sectors. Recently, CSIR-IMMT, Bhubaneswar have developed a novel state-of-the-art Technology for production of Green Steel from iron ores/fines and associated iron bearing materials like Red Mud/Mill Scales/Blue Dust, etc. This process is unique and completely environmentally-friendly and has been proved both in laboratory and bench scale. The process is fully carbon-free and the only by-product produced in the process is water. This water can be utilised in the process when the process is scaled up to commercial scale. Further efforts are underway for scaling up of the process to pilot scale in collaboration with different Small and Medium Enterprises and Iron & Steel Plants of India.

Alumina and Aluminium Sectors

During the process of digestion of Bauxite with Caustic Soda for production of Alumina utilising the Bayer's Process, Red Mud is produced, which is pumped in the slurry form and is stored in the nearby Red Mud Pond. Red Mud is considered as a Hazardous Industrial waste and Researchers have been struggling hard over the years to find out suitable avenues for bulk production of Red Mud. Red Mud contains around 50% of Fe_2O_3 and can be suitably considered as an Iron Ore. Efforts have been made for extraction of Iron from Red Mud, Production of Red Mud Cement, Red Mud Fiber Reinforced Polymer Composites for Building Components as Wood Substitute, Red Mud Bricks, Red Mud Paints and Pigments., Recovery of Titanium Oxide from Red Mud, Recovery of Alumina From Red Mud, Red Mud Soil Amending Agents, etc. However, these efforts are limited to laboratory scale only and further efforts are warranted for its bulk utilisation.

In Aluminium Sector, Spent Cathode Pot Lining Material (SPL) is generated, which is considered as a hazardous waste. This is stored with lots of safety measures as it is associated with Fluorides. This material finds application in Cement Industry and SPL Cement has been developed.

Ferro-Alloys Sectors

When we look at the Ferro-Alloys Sectors, like Ferro-Manganese, Ferro-Chrome, Ferro-Silicon, Ferro-Titanium, Ferro-Vanadium, Ferro-Nickel, etc., lots of pollutants are generated during the process of mining and also during the production of such alloys. During the mining of one tonne of Chromite, around 7 tonnes of Chromite Over Burdern (COB) is generated and which is stockpiled at the mine site, causing great environmental hazards. This Chromite Over Burden (COB) contains around 0.5 to 0.9% Ni and is considered as the only source of Nickel available in Odisha, India. CSIR-IMMT Bhubaneswar has successfully developed a technology for extraction of Nickel from Chromite Over Burden (COB) and production of Ferro-Nickel from the same. Production of Ferro-Nickel from COB has been tried out successfully both in the laboratory and Pilot Plant Scale. Production of low carbon Ferro-Manganese has also been successfully achieved. Further, Pigment Grade TiO_2 has been produced from Illimanite, Production of Fe-V and Fe-Si have also been achieved in laboratory scale.

R&D Efforts in Coal Sector

Indian coal often shows a high ash content, which is unfavourable for use in metallurgical industries. Efforts have been made by CSIR-IMMT, Bhubaneswar, to develop a novel technology to produce clean coal, zero waste technology for processing and utilisation of thermal coal, development of process for production of grapheme from natural graphite,

effect weathering on coal properties and characterisation of bore hole coal, etc. CSIR-IMMT, Bhubaneswar is considered as the National Leader in the field of Advanced Mineral Processing and has made many milestones in Mineral Processing Technology.

Efforts have been made for utilisation of Fly Ash generated from Thermal Power Plants for production of Fly Ash Cement, Fly Ash Bricks, Fly Ash- Red Mud Bricks, Fly Ash based Wood Substitute Materials, Fly Ash Tiles, Fly Ash Granite Tiles, Fly Ash as Soil Amending Agents and Alumina from Fly Ash, etc.

Normally, coal is preferred and used in Thermal Power Plants for the production of power and the major coal belts in the state are Talcher-Angul and Jharsuguda-IB Valley areas. The industrial scenario in these belts is presented in Table 7.

[illegible]

		Ib valley-BrajarajNagar-Jharsuguda		Kanhia-Talcher-Angul	
SL. No	Industrial sector	Numbers	Capacity	Numbers	Capacity
1.	Coal mines	13	44 MTPA	15	81 MTPA
2.	Thermal power plants	6	2012 MW	4	1713 MW
3.	Iron and Steel including sponge iron plants	11	2.85 MTPA	3	2 MTPA
4.	Ferro Alloys	-	-	3	0.2 MTPA
5.	Aluminium smelter	1	0.25 MTPA	1	0.345 MTPA
6.	Coal Washeries	3	6.0 MTPA	4	9.456 MTPA
7.	Other Red - B Industry	72	-	13	-
	Total	106	-	43	

Conclusion

Taking all the above points and discussions into consideration, it may be inferred that for promoting the development of Semi-Commercial Units for utilisation of industrial and mineral waste for production of value-added items under the umbrella of Technology Development Centre, concerted efforts are very much essential amongst Academia, Research Organisations and Industrial Houses for integrated and sustainable development of the state.

It is therefore of paramount importance that the industrial sectors should volunteer to take up this challenge for setting up of such Semi-Commercial Units under the umbrella "Technology Development Centre" in their premises in collaboration with Academia and Research Organisations, so that National S&T goal is achieved for all round growth and economic prosperity of the country. ■

- *Source: Metal Asia, Vol. 17, No. 2, December 2015, pp 34-41.*

Promotion of Technology Development Centre Important for Mineral Based Industries



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Due to the fast depleting nature of oil and natural gas reserves in absence of significant new discoveries, it is causing a dent in the Odisha as well as Indian economy, keeping the self-sustaineability in picture. The over-dependence on import of fossil-fuel energy has further aggravated this problem to an unimaginable level. In this paper, the efforts have been made to discuss various ways and means to promote a Technology Development Centre in Odisha to tackle the above problems noticeably and address the varying needs of mineral based industries.

Introduction

It is well known that Odisha is considered to be a major source of raw materials like iron ores, manganese ores, chromite ores, nickel ores, etc., for different industries across India and the world alike. But, there are many ores which are yet to be exploited commerically to see the likes of industrialisation. The chief reasons are absence of the possibilities to process these ores and not realising their importance in an industrial level. We cannot stop the production of various products from the industries that are already engaged in Odisha. Moreover, the research studies on such unexplored minerals can be assigned to CSIR laboratories like IMMT- Bhubaneswar, NML- Jamshedpur, etc.

Table 1: Manganese (Production quantity and value)

Quantity in tonnes; value in '000

State	2009-10		2010-11		2011-12 (P)	
	Quantity	Value	Quantity	Value	Quantity	Value
India	**2491950**	**11905233**	**3056385**	**14684000**	**2349300**	**11712864**
Andhra Pradesh	260628	332916	290785	526834	322087	535816
Goa	770	1047	440	1684	1550	2423
Gujarat	55090	27270	245240	121639	-	-
Jharkhand	39875	41472	44898	62094	18265	32766
Karnataka	301163	611165	413287	929734	136072	297422
Madhya Pradesh	607148	4094882	716285	4226787	648283	4030020
Maharashtra	613520	4618651	672828	4984603	649898	4347624
Odisha	605313	2165165	655984	3805668	565662	2451830
Rajasthan	8443	12665	16638	24957	7483	14963

Table 2: Chromite (Production quantity and value)

Quantity in tonnes; value in '000

State	2009-10		2010-11		2011-12 (P)	
	Quantity	Value	Quantity	Value	Quantity	Value
India	**3425580**	**10453620**	**4325699**	**25964208**	**3764120**	**26523121**
Karnataka	6483	30856	8540	33223	9827	40336
Maharashtra	66	489	-	-	-	-
Odisha	3419031	10422275	4317159	25930985	3754293	26482785

Even though, the basic research studies are complete, there remains a mid-way before the process or technology developed in lab scale goes to industry. For example, the innovative technological routes for production of Ferro-nickel and Ferro-vanadium have restricted their boundary of operation to lab scale due to absence of scaling-up facilities. Yes, that is the pilot scale testing which must be conducted prior to the jump of the new process or technology to industrial level. This is where the concept of Technological Development Centre comes to scene which can help



(Quantity in '000 tonnes; value in ₹ '000)

State		2009-10		2010-11		2011-12 (P)	
		Quantity	Value	Quantity	Value	Quantity	Value
India	Total	218553	264620052	207157	396141714	167289	379651367
	Lumps	90262	126412246	77273	173545279	62700	179737036
	Fines	127720	137815781	129203	222181727	104180	199634866
	Concentrates	571	392025	681	414708	409	279465
Andhra Pradesh	Total	6246	8101303	1560	478212	1714	571872
	Lumps	3249	4684328	1128	392500	1263	452954
	Fines	2997	3416975	432	85712	451	118918
Chhattisgarh	Total	26211	44227248	29320	71712050	30455	96429439
	Lumps	11191	23572505	12067	36122684	11556	47229745
	Fines	15020	20654743	17253	35589366	18899	49199694
Goa	Total	38136	55846319	35564	74912294	33372	69492708
	Lumps	8267	11145773	7619	12568654	6790	12879951
	Fines	29298	44308521	27264	61928932	26193	56345292
	Concentrates	571	392025	681	414708	389	267465
Jharkhand	Total	22547	11242048	22288	16907241	18942	19132126
	Lumps	10249	5766639	9611	9224281	8059	9757217
	Fines	12298	5475409	12677	7682960	10883	9374909
Karnataka	Total	43163	48811665	38983	79098120	13189	29821352
	Lumps	16337	19013755	14074	26268567	4806	14521206
	Fines	26826	29797910	24909	52829553	8363	15288146
	Concentrates	-	-	-	-	20	12000
Madhya Pradesh	Total	1058	359750	1762	785316	1102	719850
	Lumps	117	46591	234	118743	104	100813
	Fines	941	313159	1528	666573	998	619037
Maharashtra	Total	283	221777	1525	1332628	1470	1302353
	Lumps	190	149047	1046	774643	1051	752247
	Fines	93	72730	479	557985	419	550106
Odisha	Total	80896	95807348	76128	150907681	67013	162172471
	Lumps	40649	62031014	31467	88067035	29039	94033707
	Fines	40247	33776334	44661	62840646	37974	68138764
Rajasthan	Total	13	2594	27	8172	32	9196
	Lumps	13	2594	27	8172	32	9196

(Quantity in tonnes; value in ₹ '000)

State	2009-10		2010-11		2011-12	
	Quantity	Value	Quantity	Value	Quantity	Value
India	1300772	177376	1220304	147948	1665820	226797
Andhra Pradesh	596318	60449	633253	70005	1022873	133828
Gujarat	184840	8343	234548	15733	208058	19151
Jharkhand	5084	667	1220	183	1550	310
Karnataka	203378	69711	130300	17119	149600	21111
Kerala	69171	15322	88444	34913	110992	41210
Madhya Pradesh	133080	7269	132539	9995	166247	10634
Maharashtra	108901	15615	-	-	6500	553

scaling up the laboratory studies to pilot scale level before it finally becomes possible for the new innovative technology to be commercialised completely through industries. Through this Technology Development Centre, the research works will find their way to application based output instead of mere scientific paper publications that hardly contribute to the progress of our nation.

Source of Minerals

There are various types of minerals available in Odisha, namely, manganese, chromite, iron, nickel, vanadium, bauxite, monazite, etc. Their different sources statewise have been indicated in terms of production values and some reserves from Table 1 to 10.

Source of Mineral Based Industries in India

Based on our mineral sources, different mineral based industries were planned in India. The statewise, plantwise capacities and their specification of principal Ferro-alloys produced in India are indicated in Table 12.

(In million tonnes)

Grade/State	Total reserves (A)	Remaining resources						Total resources (A+B)
		Pre-feasibility		Measured	Indicated	Inferred	Total	
		STD221	STD222	STD331	STD332	STD333	(B)	
All India : Total	-	21	21	31	53	63	189	189
By Grades								
+ 0.9 % Ni	-	13	8	-	18	3	42	42
05 to 0.9% Ni	-	8	13	31	21	21	94	94
(+) 0.5% Ni. unclassified	-	-	-	-	14	39	53	53
Not-known	-		-	-	-	-	-	-
By States								
Jharkhand	-	-	-	-	2	7	9	9
Karnataka	-	-	-	-	-	++	++	++
Nagaland			-	-	-	5	5	5
Odisha	-	21	21	31	51	51	175	175

Figures rounded off

(In tonnes)

State	2009-10	2010-11(R)	2011-12 (P)
ILMENITE			
India : Total	**713605**	**663217**	**751163**
Kerala	133832	113240	86454
Odisha	2 10031	206139	188000
Tamil Nadu	369742	343838	476709
RUTILE			
India : Total	**18573**	**26593**	**16598**
Kerala	6607	5969	5664
Odisha	8033	8043	7874
Tamil Nadu	3933	12581	3060

(Quantity in tonnes; value in ₹ '000)

State	2009-10		2010-11		2011-12 (P)	
	Quantity	Value	Quantity	Value	Quantity	Value
India	**14124093**	**4887897**	**12722820**	**5122151**	**12877394**	**5520032**
Chhattisgarh	1687069	607911	2109949	777273	2365304	1268221
Goa	31050	3105	100900	10090	84700	8470
Gujarat	2687306	667424	938574	570664	843497	430400
Jharkhand	1670577	673016	1855993	627327	1830850	692085
Karnataka	123316	32748	64643	11348	83019	20157
Madhya Pradesh	1056847	365097	616319	262437	617146	205571
Maharashtra	1985006	628556	2133736	549201	1937898	505268
Odisha	4879580	1909188	4856808	2305022	5045888	2372555
Tamil Nadu	3342	852	45898	8789	69092	17305

(In tonnes)

Grade/State	Reserves			Remaining Resources					
	Proved STD111	Probable STD122	Total (A)	Pre-feasibility STD221	Pre-feasibility STD222	Indicated STD332	Inferred STD333	Total (B)	Total resources (A+B)
All India: Total									
By Grades									
Ore	293539	117416	410955	1720000	4000000	232000	18355933	24307933	24718888
Contained V_2O_5	1144.8	457.92	1602.72	2835	5600	487.2	54362.25	63284.45	64887.17
By States									
Karnataka									
Ore	-	-	-	500000	4000000	-	14884430	19384430	19384430
Contained V_2O_5	-	-	-	700	5600	-	43197.55	49497.55	49497.55
Maharashtra									
Ore	293539	117416	410955	-	-	-	58708	58708	469663
Contained V_2O_5	1144.8	457.92	1602.72	-	-	-	229	229	1831.72
Odisha									
Ore	-	-	-	1220000	-	232000	3412795	4864795	4864795
Contained V_2O_5	-	-	-	2135	-	487.2	10935.74	13557.94	13557.94

Figures rounded off

(Quantity in '000 tonnes; value in ₹ '000)

State	2009-10		2010-11		2011-12 (P)	
	Quantity	Value	Quantity	Value	Quantity	Value
India	**532042**	**513182400**	**532694**	**620210400**	**539950**	**701719100**
Public sector	484040	461918400	485061	525347400	490755	594510600
Private sector	48002	51264000	47633	94863000	49195	107208500
Andhra Pradesh	50429	67373100	51333	81106100	52211	90008100
Arunachal Pradesh	251	894300	299	1106000	221	1464100
Assam	1113	3965200	1101	4072600	602	3988000
Chhattisgarh	109953	50308300	113824	58256200	113958	70740300
Jammu & Kashmir	23	18600	24	22400	20	42500
Jharkhand	105917	114630000	108949	185716200	109566	139887600
Madhya Pradesh	74074	84933100	71104	93673600	71123	83305500
Maharashtra	41005	50887500	39336	53628800	39159	53112600
Meghalaya	5767	20545600	6974	25796800	7206	47739800
Odisha	106409	58751300	102565	73545300	105476	96399000
Uttar Pradesh	13968	15067800	15526	15122300	16178	34369500
West Bengal	23133	45807600	21659	28164100	24230	80662100

Source: Coal Directory of India, 2011-12, Coal Controller's Organisation, Kolkata

As the electric power is the major source of raw materials in ferro-alloys making, these ferro-alloy industries are facing a lot of problems due to high power tariff in our country. Other constraints have been the increase in cost of imported coke, higher cost of transportation in the country and frequent increase in cost of diesel.

Evolution of the Concept

During his tenure in mega steel projects like Rourkela Steel Plant and Bokaro Steel Plant of SAIL and his association with various metallurgical industries as Managing Director & Chairman of IDCOL and IPICOL of Odisha, Dr. H. P. Mishra felt the necessity of promoting Technology Development Centres which will provide lease for our talented professionals of various disciplines to propose and invent technologies to exploit the mineral resources of our state commercially which is otherwise wasted. Technology Development Centre will utilise innovative skills of our talented engineers to invent better process technology, equipment design, and new alloy for providing competitive skill in global market. China is more competitive in global market because its trained

(Quantity in tonnes; value in ₹ '000)

State	2009-10		2010-11		2011-12 (P)	
	Quantity	Value	Quantity	Value	Quantity	Value
India	**5911759**	**1672224**	**5839710**	**1870047**	**5416817**	**1521320**
Andhra Pradesh	1577072	317824	1216373	363958	981800	282084
Chhattisgarh	1286514	335580	1592838	363551	1628165	394952
Gujarat	346234	50554	244218	45935	169235	23768
Jharkhand	422019	379817	429866	386879	190769	171692
Karnataka	385041	55044	442941	71522	548694	90517
Madhya Pradesh	277017	36190	279859	41788	360907	51785
Maharashtra	76625	15566	64865	13867	127857	29095
Odisha	1316371	450677	1358156	551985	1174594	437571
Rajasthan	224803	30966	210498	30553	234709	39848
Uttarakhand	63	6	96	9	87	8

human material is engaged in innovative work in various fields especially for the manufacture of the products in electronic, mechanical, household and construction area. Technology Development Centre will provide the lease for unfolding the latent skill of our engineers in different segments and the creation of job opportunities will empower our economy with the real strength for its sustenance.

(In million tonnes)

State	Resources*
All India	**10.70**
Andhra Pradesh	3.74
Bihar	0.22
Kerala	1.51
Odisha	1.85
Tamil Nadu	2.16
West Bengal	1.22

Source: Department of Atomic Energy, Mumbai.
* Inclusive of indicated, inferred and speculative categories.

The Possible Approach

Efforts have been made towards establishing a Technology Development Centre at Kalinganagar, Odisha in collaboration with TISCO. This can start with establishing of semi-commercial units for the manufacture of Ferro-Nickel, Ferro-Vanadium, and other sophisticated alloys based on which the projects for the commercial plants can be worked

(In tonnes)

Name & Location of the Plant	Product	Specifications	Installed capacity
Andhra Pradesh			
Andhra Ferro Alloys Ltd. Srinivasanagar, Dist. Vizianagaram	HC ferro-chrome	Cr: 60-65% Si: 24% C: 6-8% P: 0.040% S: 0.040%	20000
Ferro Alloys Corporation Ltd. Shreeramnagar, Dist. Vizianagaram	Ferro-manganese Ferro-chrome Silico-manganese Ferro-silicon Silico-chrome Other ferro-alloys	N/A Cr: 60-63% Si: 3-4% C: 6-8% P: 0.03-0.05% (max.) S: 0.03-0.05% (max.) - N/A N/A N/A	72500 (For all ferro-alloys)
Jindal Stainless Ltd. (Ferro Alloys Division) Jindal Nagar, Kothavalasa Dist.Vizianagaram	HC ferro-chrome	Cr: 62% Si: 2.5% C: 7-8% P: 0.040%	40000
GMR Technologies & Industries Ltd. Village Ravivalasa Dist. Srikakulam	LC ferro-manganese MC ferro-manganese HC ferro-manganese Silico-manganese Ferro-silicon LC ferro-chrome HC ferro-chrome Silico-chrome	Mn: 60% Si: 16% S: 0.05% P: 0.5% Cr: 60-68% Si: 2.0 to 4% P: 0.03% S: 0.05%	25000 (Total) -
VBC Ferro Alloys Ltd. Village Rudraram Dist. Medak	Ferro-silicon HC ferro-chrome	- -	19000 18000
Nav Bharat Ferro Alloys Ltd. E.M.D., Paloncha, Kothagudem Dist. Khammam	HC ferro-chrome Silico-manganese Ferro-silicon	Cr: 60% (min.) Si : 34% (max.) C: 6-8% P: 0.03% (max.) S: 0.03% (max.) Mn: 60-70% Si: 15-16% (min.) C: 2% (max.), P: 0.03% (max.) Si: 0.03% (max.) Si: 40-45%, 70-75%, 75-80%	12491 9581 9309

Contd...

(in tonnes)

Name & Location of the Plant	Product	Specifications	Installed capacity
		Al: 0.5% (max.), 1.25% (max.) C: 0.15% (max.) P: 0.05% (max.) S: 0.05% (max.)	
Sree Sarda Alloys Ltd. Ravivalsa, Tekkali Mandal Dist. Srikakulam	Ferro-chrome	N/A	6000
Chhattisgarh			
Hira Group of Industries Jain Carbides & Chemical Ltd. (i) Unit 1, Urla, Dist. Raipur	HC ferro-manganese	Mn: 70-75% Si: 1.5% (max.) C: 6-8% (max.) P: 0.40% (max.) S: 0.05% (max.)	7000
	Silico-manganese	Mn: 60-65%, Si: 13-17% (max.) C: 2.5% (max.), P: 0.35% (max.) S: 0.03% (max.)	6000
(ii) Unit 2	HC ferro-manganese Silico-manganese	 Mn: 60-65%	14000 12000
(iii) Hira Ferro Alloys Ltd. Urla, Dist. Raipur.	Ferro-manganese Silico-manganese	N/A N/A	10000 7000
(iv) Alok Ferro Alloys Ltd., Raipur.	Silico-manganese	N/A	18000
Sarda Energy & Minerals Ltd. (Formerly Raipur Alloys & Steel Ltd.)	Ferro-manganese Silico-manganese	- -	- -
Chhattisgarh Electricity Co. Ltd. Siltara, Raipur	HC ferro-manganese	Mn: 70-75% Si: 1.5-2.0% C: 6.0-8.0% P: 0.35-0.40% S: 0.05% (max.)	36000
	Silico-manganese	Mn: 60-65% Si: 15-20% C: 2.0-2.5% P: 0.3-0.35% S: 0.05% (max.)	N/A
Nav-chrome Ltd. Urla Industrial Area, Dist. Raipur	HC ferro-manganese Silico-manganese HC ferro-chrome	N/A N/A N/A	21560 N/A 14700
Deepak Ferro Alloys Ltd. Urla Industrial Area, Raipur	HC ferro-chrome	Cr: 60-70% Si: 2 to 4%, S: 0.05% C: 6 to 8%	5000
Jindal Steel & Power Ltd., Raigadh	HC ferro-chrome	Cr: 60-66% C: 6 to 8% Si: 4% max. P: 0.050% max. S: 0.050% max.	36000
Goa			
Karthik Alloys Ltd.	N/A	N/A	4100
Gujarat			
Essel Mining & Industries Ltd. Vapi, Dist. Valsad	Ferro-vanadium	V: 50% C: 0.1% (max.) S and P: 0.05% each Al: 1.5%	400
	Ferro-molybdenum	Mo: 60% C: 0.1% S: 0.08% P: 0.06% Al: 0.5%	1200
	Ferro-titanium	N/A	600
Electro Ferro Alloys (Pvt.) Ltd. Ahmedabad, Gujarat Baroda Ferro-Alloys, Dist. Panchmahal	Ferro-molybdenum Ferro-silico-zirconium HC ferro-chrome	N/A N/A	300 3500
Haryana			
Haryana Ferro-Alloys Ltd.	-	-	2500
Jharkhand			
Anjaney Ferro Alloys Ltd. Mihijam Dist. Dumka	Ferro-silicon Silico-manganese Ferro-manganese	N/A N/A N/A	N/A N/A N/A
Gautam Ferro Alloys Ltd. Ramgarh Industrial Area, Marar Dist. Hazaribagh, Bihar	-	-	5500

Contd...

(In tonnes)

Name & Location of the Plant	Product	Specifications	Installed capacity
Karnataka			
Sandur Manganese & Iron Ore Ltd Vyasanakere, Dist. Bellary (Plant closed since 1.8.1998)	HC ferro-manganese Silico-manganese Ferro-silicon		29100 20000 24000
Dandeli Steel & Ferro Alloys Ltd. Dandeli, Dist. Uttar Kannada	Ferro-manganese MC ferro-manganese	Mn: 70-75% C: 0.1% Si: 24% P: 0.15% S: 0.05% Size: 37 mm Mn: 70-75% C: 1.5% P: 0.25% Si: 2% S: 0.05%	6000
S.R. Chemicals & Ferro-alloys KIADB Honaga, Belgaum	LC Ferro-manganese	Mn: 70% C: 0.1% P: 0.12%	25
Thermit Alloys (Pvt.) Ltd. KSSIDC Industrial Estate Shimoga	Ferro-manganese Silico-manganese Ferro-chrome Ferro-silicon Silico-chrome	N/A N/A N/A N/A N/A	1200
Kerala			
Silcal Metallurgic Ltd. Wayalur, Dist. Palakkad	Silico-manganese	Mn: 70-75%	3600
INDSIL Electrosmelts Ltd. Pallatheri, Dist. Palakkad	Silico-manganese Ferro-silicon	N/A N/A	N/A N/A
Shri Laxmi Electro Smelters (Pvt.) Ltd. Industrial Development Area Erumathala, P.O. Aluva	Ferro-silicon	N/A	N/A
Madhya Pradesh			
Manganese Ore (India) Ltd. Ferro-manganese Plant Bharweli (Manjhara), Dist. Balaghat	HC ferro-manganese	Mn: 78±1% P: 0.35% (max.) C: 6.8%	10000
Jalan Ispat Castings Ltd Industrial Area Meghnagar, Dist. Jhabua	Silico-manganese	Mn: 60-65% Si: 15-20% C: 2% (max.) P: 0.35%	12000
Crescent Alloys Pvt. Ltd. Seoni	Ferro-silicon Ferro-manganese	N/A N/A	4500 (Total)
Maharashtra			
Maharashtra Electrosmelt Ltd. Mul Road, Chandrapur	HC ferro-manganese MC ferro-manganese Silico-manganese	Mn: 70-74% Si: 1.5% (max.) C: 6.8% P: 0.43% (max.) N/A N/A	100000 (Total)
Nagpur Power & Industries Ltd. P.O. Khandelwalnagar Dist. Nagpur	Silico-manganese HC ferro-manganese	Mn: 60-65% P: 0.35% Mn: 70-75% P: 0.4%	N/A N/A
Bharat Pulverising Mills Ltd. Andheri, Mumbai	Ferro-molybdenum Ferro-tungsten Ferro-vanadium	N/A N/A N/A	200 (Total)
Sunbel Alloys Co. of India Ltd. Thane-Belapur, Mumbai	Ferro-molybdenum Ferro-silicon Ferro-tungsten Ferro-vanadium	N/A N/A N/A N/A	300 (Total)
Natural Sugar and Allied Ind. Ltd. Sainagar, Ranjani, Dist. Osmanabad	HC Ferro-manganese Silico-manganese	Mn: 70-75% Si: 2-2.5% P: 0.4% C: 6-8% Mn: 60-65% Si: 13-15% P: 0.3% C: 2-2.5%	(5 MVA) (6 MVA)

Contd...

(in tonnes)

Name & Location of the Plant	Product	Specifications	Installed capacity
Odisha			
Ferro Alloys Corporation Ltd. (Charge-chrome Division) Randia Dist. Bhadrak	HC Ferro-chrome Charge-chrome	Cr: 60-64% Si: 34% S: 0.03-0.05% (max.) P: 0.03-0.05% (max.) C: 6-8%	50000 65000
Tata Steel Ltd. Ferro-manganese Plant, Joda, Dist. Kendujhar	HC ferro-manganese Silico-manganese	Mn: 68-73% Mn: 46-48% Si: 14.56%, P: 0.197%	30500 NAS
Tata Steel Ltd., Ferro Alloy Plant Bamnipal, Dist. Kendujhar	HC Ferro-chrome Charge-chrome	Cr: 60 (min.) Si: 4% (max.) C: 8% (max.) P: 0.03% (max.) S: 0.03% (max.)	50000
Balasore Alloys Ltd. Balgopalpur, dist. Balasore, Odisha (Formerly Ispat Alloys Ltd.)	Ferro-manganese Silico-manganese Ferro-chrome	Mn: 70-75% Mn: 60-65% & 65-70% Cr : 60-65%	100000 (Total)
Jeypore Sugar Co, Ltd. (Ferro-manganese Plant) Dist. Rayagada	HC ferro-chrome Silico-manganese	Cr: 60-65% P: 0.055% C: 2% S: 0.05% Si: 4% Fe: Balance Mn: 60-65% Si: 15-18% C: 2% (max.)	22000 22000
IDCOL Ferro Chrome & Alloys Ltd. Jajpur Road, Dist. Jajpur	LC ferro-chrome	Cr: 62-65% Si: 1.5 to 8% C: 8% (max.)	18, 000
Indian Charge Chrome Ltd. Choudwar, Dist. Cuttack	HC ferro-chrome Charge-chrome	Cr: 60%	62500
Indian Metals & Ferro Alloys Ltd. (IMFA), Therubali, Dist. Rayagada	Ferro-silicon HC ferro-chrome	Si: 70-75% Cr: 60%	53000 195000
Superb-Metal Alloys (Pvt.) Ltd. Rairangpur, Dist. Sundergarh	Ferro-columbium Ferro-molybdenum Ferro-tungsten Ferro-vanadium	N/A	300 (Total)
Puducherry			
Silcal Metallurgic Ltd.	Ferro-silicon Ferro-silicon-magnesium	- -	10560 1800
Snam Alloys (Pvt.) Ltd. Kariamanickam Dist. Puducherry	Ferro-silicon	N/A	4000
Punjab			
Mehra Ferro-Alloys Verka, Amritsar	Ferro-molybdenum Ferro-vanadium Ferro-titanium Ferro-tungsten Ferro-boron	N/A	300 (Total)
Sikkim			
Akshay Ispat & Ferro Alloys Ltd. Manning, Dist. Namchi	Ferro-silicon	N/A	6000
Tamil Nadu			
VSK Ferro Alloys Ltd. Thuthipet	Ferro-silicon	Si: 72.3% C: 0.15% S: 0.051% Mn: 0.55% P: 0.042% Fe : 26.127%	3000
Uttar Pradesh			
The India Thermit Corpn. Ltd. Fazalganj, Kanpur	Ferro-molybdenum Ferro-titanium Ferro-chrome Ferro-boron Chromium metal LC ferro-manganese Ferro-vanadium	N/A	300 (Total)

Contd..

(In tonnes)

Name & Location of the Plant	Product	Specifications	Installed capacity
Hindustan Ferro-Alloys Hamirpur	Ferro-silicon	N/A	3200
West Bengal			
Cosmic Ferro Tech. Ltd. Dist. Bankura, Bishnupur	HC ferro-manganese Silico-manganese	Mn: 66-71% Si: 1.4% C: 6.5-7% P: 0.3% Mn. 61-65%, Si: 15.5% C: 1.9%, P: 0.28%	45375
Gayatri Minerals Pvt. Ltd., WBIIDC Growth Centre, Bishnupur, Bomkura (WB)	Silico-manganese	Mn: 60% (min.) Si: 14-16% C. 2% (max.)	
Karthik Alloys Ltd. (I & II) Durgapur	Silico-manganese	N/A	7300
Maithan Alloys Ltd. Burdwan	Ferro-manganese Silico-manganese Ferro-chrome	N/A	52600 (Total)
Monnet Ferro Alloys Ltd. Burdwan	Silico-manganese	N/A	12500
Shyam Ferro Alloys Ltd. Burdwan	HC silico-manganese HC ferro-manganese HC ferro-chrome	N/A	100000 (Total)
Shri Vasavi Industries Ltd. WBIIDC Industrial Growth Centre Bishnupur, Dist. Bankura	HC ferro-chrome	Cr: 62% Si: 3-5%	45000
Modern India Con-Cast Ltd. WBIIDC Industrial Growth Centre, Bishnupur, Dist. Bankura	Bulk ferro-alloys	-	22000
Rohit Ferro Tech. Ltd Bishnupur, Dist. Bankura	HC ferro-chrome	Cr: 60% (min.) C: 8% (max.) Si: 3.5% (max.) P: 0.03% (max.) S: 0.04% (max.)	45375

Note: HC : High carbon MC : Medium carbon LC : Low carbon
Source: Information collected by IBM on non-statutory basis

out by consultants like MECON Ltd., M.N. Dastur, etc. Besides mineral area, the Technology Development Centre can also be established at Paradeep for new petro-chemical products based on paradeep refinery of Indian Oil.

Immediate Benefits

The Technology Development Centre will utilise the laboratory and Pilot scale work of our research laboratory for establishing commercial units in various fields and thus may bridge the gap between research laboratories of CSIR like IMMT- Bhubaneswar, NML- Jamshedpur and industries which hinders our growth in different fields. The future prospects will be bright, if the concept is extended in various areas where our manufacturing activities based on human skills are roped in with innovative skills to sustain the business in global competition.

Locating the [illegible] Sites

Kalinganagar is the most appropriate location because there are a number of metallurgical units like NINL, JINDAL, and VISA where products are made market-ready. Similarly, Technology Development Centre can be established by National Aluminium Company in Damanjodi and Angul to reinvent different process parameters and products to improve the technological and financial base of our aluminium industry.

Conclusion

Hence, it is concluded that the impórtance as well as the need of a Technological Development Centre should be realised. This approach will not only explore the rich mineral reserves sitting idly in different parts of Odisha but also pave a right path for their meaningful utilisation in various industries. Further, this will enhance the productivity of various industries and encourage unlocking of several employment opportunities. Above all these benefits, a self-sustaining mode of production of various application-driven products will invite a balance to India's economy.

Technology Management Essential for Industrialisation of our Country





Dr. Ing. H.P. Mishra
Former Chairman, IPICOL, Bhubaneswar

Technology may be defined as an ongoing process of the innovative effort of human ingenuity to utilise science for safety and sustenance of human society. From the very beginning of human civilisation, continuous attempts have been made to develop technology for reducing human strain and stress for various productive operations. Therefore, the management of technology is an inseparable part of human life and one must understand this in depth. Its management can provide better knowledge in all fronts to attend reasonable living standard for its people. For this, you will agree that deep national commitment is called for because it is not just to provide elite living for few but the effect should percolate down the line to the multitude for which the government and society should have utmost concern.

Technology management can be grouped into three categories:

1. Technology borrowing
2. Technology absorption
3. Technology generation

Technology borrowing has been practised in our country for last four decades. In 1955, Hindustan Steel Plant entered into an agreement with number of foreign companies like Krupp, Demag, Mannesmann, etc. to obtain technology and also equipment. At that time, our late Prime Minister Pandit Jawaharlal Nehru had the foresight to encourage consultancy organisation in the field of steel, fertiliser, etc. to get the technology absorbed in our system. Machine building industry like Heavy Engineering Corporation was set up to manufacture machinery for steel and other plants. At that point, the planning was to set up one million tonne/yr. capacity steel plant every year. Similarly in fertiliser field, planning and design cell of FCI was created to Indianise foreign technology both in public and private sector. Some of the fine machine building

units were also installed. This infrastructure was created with the sole idea of not only to borrow technology from abroad but to get it absorbed in our system. However, in spite of all infrastructure facilities, our trading culture denied its absorption. For quick trading and earning money, these facilities were not fully utilised in some pretext or other. This has resulted in our dependence on borrowing technology and also equipment. The base for any development, the skilled and super-skilled man-power was not fully geared for quality technological activities and some of our best brain migrated to other countries for mainly professional satisfaction besides better living.

Technology absorption is one of the valuable tools for speedy developing countries like Japan, South Korea, which have prepared the base with highly talented professional and providing motivation at every stage. Their professionals and industrialists with deep national commitment have taken pride in national welfare. Their industrialists have proper leadership to retain these professionals.

In our country for last two decades, the operational environment has undergone great deterioration where unscrupulous entrepreneurs and professional can survive. Today in the name of liberalisation, free import of many technologies is taking place and there is no proper effort to absorb the same in our system. The entrepreneur for temporary prosperity takes recourse to trading ignoring the long-term interest of our country.

Technology generation and management depend on the quality of our self-reliant system and the support it receives from the government and the industrial community. It may be considered a stage higher than technology absorption. In today's competitive world, this will constitute the real strength of a country's economy and also defence. In this effort, the national commitment will provide the best motivation for technology generation. For example, Japan and South Korea have not only absorbed the foreign technology but have refined and developed these as their own which have given them unique position in competitive commercial world. Technology commercialisation can only be a step higher and our system through our skilled and professional community makes dedicated effort to produce quality good at cheapest cost for the world community.

For commercialisation of technology, serious efforts should be made to bring effective coordination between our technological laboratories, consulting organisation and industry. This will only be possible if a conscious decision at national level is taken on the following:

1. Laboratories, consulting organisation and industry should provide a system where talented professionals will be circulated to have proper exposure to the need of our industry.
2. Industries with process technologies available in the country or borrowed from abroad should try to create a team under the care of a consulting organisation to market in India and abroad. As for example, NALCO, BALCO, SAIL, etc. have imported technologies but when modernisation or expansion takes place, they lean heavily again on import of both technology and to certain degree on equipment. In a running plant, the talent of our professional engineers is not fully utilised as in case of a consulting engineering organisation which provides basic technology and detailed design and engineering.
3. A proper team with financial and commercial background should be associated in all our activities of technology promotion to fix a value to our effort at various stages and to compute it in commercial term for marketing the same, nationally and internationally.
4. Under the present stage of industrialisation, lot of innovative efforts being made in our laboratory for creating commercial projects but many times they do not succeed due to lack of appropriate data relevant to commercial project. This can be provided by promoting Technology Development Centre where semi-commercial plants can provide the appropriate data for preparing in detail project report.

Finally, it may be relevant to mention that in all these operations, talented dedicated professionals with national commitment are most important ingredients to attend self-reliance in technology management. Our social and political value system should promote this. Otherwise, the country cannot withstand ever-increasing global competition.

- *Source: Iron and Steel Review, Vol. 58, No. 5, October 2014, pp66-68.*

CHAPATER 3

Development of Iron and Steel Based Industries



Future Growth of Iron and Steel Industry

The Iron and Steel making process intensively uses minerals and energy besides the capital cost. Steel making is one of the most intensive consumers' energy in the manufacturing sector. The steelmakers need to be sensitive to customer demands in terms of product, properties, quality, prices and delivery due to highly competitive market, guided by rapid technological change and accelerating market globalisation. It also faced severe environmental concerns arising out of high global steel output of 1200 million tonnes per annum and the last 30 years have shown that the technology of steel making has and can change rapidly on a global scale. The environmentally friendly and greener technologies along with minimum cost and highest quality shall only sustain in time to come. The grey shall be produced by the green and blue sky shall continue to remain blue.

There are four technology drivers influencing the steel sector and these are: High capital cost, Raw material shortage, Environmental issues and Customer demand. The biggest challenge is to evolve appropriate technology as a roadmap through research and development for subsequent transfer to users.

Improvisations in established routes of Iron & Steel making

Direct Reduced Iron (DRI) & Blast Furnace for Iron making and Basic Oxygen Furnace & Electric Furnace (Electric Arc & Induction) are by far the most established processes used worldwide. Blast furnace in various forms has remained the backbone of iron production for more than 200 years to yield carbon saturated hot metal for subsequent processing by steelmakers. However, the modern blast furnace has undergone basic process and technological changes vis-à-vis its earlier ancestors. Injection of pulverised coal, natural gas, oil and in some cases recycled plastic is used as substitute for a portion of metallurgical coke as a primary reductant and source of chemical energy represents an important development in this direction. Coke making is extremely problematic from an environmental perspective as many of the hydrocarbons driven off during the coking process are hazardous. Also not all types of coal are suitable for the production of coke. Improvement in process control and reduced refractory wear has increased blast furnace campaign life significantly, which is critical to the economics of the process. The current expected lifetime of newly rebuilt furnaces is 20 years or greater.

There has been a rapid increase in the production of iron via DRI process over last 10 years. Further, the basic open-hearth process has been almost completely replaced worldwide by various top, bottom or combination blown Basic Oxygen Steel Making processes over the last 40 years. This has improved

productivity and efficiency of oxygen steel making vessels. The abandonment of open-hearth steel making practices for steel-making was also accompanied by a parallel widespread departure from ingot casting to the continuous casting of steel. This has a dramatic effect on steel industry worldwide. Between 1960's and now, continuously cast steel as a percentage of a total steel production has risen from essentially 0 per cent to more than 90 per cent in most countries.

With lower capital cost than an integrated mill, mini mills based on electric arc furnace melting of scrap were able to establish a cost advantage in the production of certain steel production. The development of ultra high powered electric arc furnace and reliable billet and bloom continuous casting machine provided a low cost route for the production of lower quality steel long products, such as reinforce bar and structural steels. As a result, integrated steel producers have been completely displaced from these low-end segments of the steel market in developed countries and has allowed them to focus on the production of high quality plate and thin gauge flat products. Though global DRI capacity via existing gas based technology is likely to increase further in order to support expansion of EAF steel making to new quality products, the blast furnace is expected to remain the mainstay of global iron production for several decades. Hence, further improvements in blast furnace technology are warranted.

Further improvements expected in the processes of Iron Making

It is noteworthy that a great opportunity exists to develop an entirely new process that better fits the needs of contemporary and future steelmakers as the supply of coke gets more and more constrained, causing closure of smaller blast furnaces but the need for additional hot metal capacity continues to rise. The characteristic of a new and ideal process for increased iron unit production should include the following:

- Very high efficiency with respect to energy and materials usage.
- Greater flexibility in feed materials.
- Reduced capital costs.
- Operational flexibility.
- Capacity of producing steel or low carbon iron directly.

Latest processes for iron making like Corex, HIsmelt and Finex technologies are slowly finding commercial operations. These technologies need to be improved and evolved based on problems at the application level.

Pollution Prevention and Control

In addition to upgrading iron and steel making technologies, adoption of various pollution prevention and control measures are inevitable.

It is possible to re-use over 90 per cent of the waste water generated after proper treatment. Discharged waste waters should in all cases be targeted less than 5 m^3/t of steel manufacturing and efforts should be made to bring it less than 1 m^3/t. As regards solid waste, the blast furnace slag should normally be generated at a rate of less than 320 Kg/t of iron, with target of 180 Kg/t. Acute focus on energy recovery in various processes of iron and steel making is absolutely necessary.

The technologies related to waste heat recovery like waste heat recovery boilers, organic rankine cycle, phase change materials need to establish and mature them on war footing. Using photo cells for energy recovery from huge radiation losses during various processes and harvesting wind energy for steel making also should be given high priority by researchers and technology suppliers.

The greenest technologies and operating plants shall subsequently survive. The wakeup call is already there in the form of global warming and for those who do not wake up, the darkness is never going to end. This one issue for sure is going to rule the iron & steel scenario for a very long time and the technology suppliers and steel producers who focus on this issue from today will be the winners of tomorrow.

Technologies for various treatments

Appropriate treatment technologies for air emission, waste water and solid wastes are integral to good manufacturing practices. Air emission control technologies for removal of particulate matter include scrubbers, bag houses and Electrostatic Precipitators (ESPs). Waste water treatment systems typically include sedimentation to remove suspended solids, precipitation of heavy metals, through physical or chemical treatment and filtration. Solid waste treatment involves stabilisation of heavy metals using chemical agents before disposal.

Compliance with Emission Guidelines

The key production and control practices which will lead to compliance with emissions guidelines are summarised as under:

- Prefer the direct steel manufacturing process wherever technically and economically feasible.
- Use pelletised feed instead of lump feed wherever appropriate.
- Replace a portion of the coke used in the blast furnace by injecting pulverised coal or by using natural gas or oil.
- Achieve high-energy efficiency by using blast furnace and basic oxygen furnace off-gas as fuels.
- Implement majors (Such as encapsulation) to reduce the formation of dust, including iron oxide dust and wherever possible recycle the collected to a sintering plant.

- Treat and re-circulated waste waters.
- Use slag in construction materials to the maximum extent possible.

Future and growth of Mining and Steel

Based on cumulative output of 62 countries who report their data to World Steel Association, world crude steel production in March 2012 stood at 132 million tonnes. By March 2013, the output increased to 135 million tonnes, registering a growth of 1.0 per cent. Though there was an increase of crude steel in March 2013, a major decline was registered in South Korea, European Union (Germany, Italy, Spain, France and Turkey), U.S.A., Russia, Ukraine and Brazil, while India registered a positive growth of 6.5 per cent over the same period. This worldwide decline was on account of local recession amidst the year 2008.

However, steel being a vital component in the global economy's production chain, steel industry is expected to adjust to the changed market condition. The economists expect that the global recession will stabilise soon within the financial year 2013-14.

There is a strong correlation between the growth rates of economy and demand for steel. The optimistic growth rate in the emerging economies of China, India, Russia and Brazil are expected to generate demand for steel and support the global steel industry. The world average per capita consumption of steel is approximately 200 Kg. The consumption is high in developed countries and is at near saturation level. India's per capita consumption stands as low as 59 Kg, while China consumes around 500 Kg per capita. These two countries, which are expected to see increased per capita consumption, will drive the demand. Hence, over the long-run, the global demand for steel can be projected to be higher than current levels.

The growing steel industry will come to face wide ranging environmental concerns that are fundamentally related to consumption of raw materials with intrinsic carbon contents, high quality of energy requirement and the byproducts associated with quantum of steel production. The change therefore is to improve upon the technologies that will bring about reduced consumption of energy, reduced consumption of raw materials and reduced levels of emissions besides being cost-effective. Steel being one of the major energy consumers in the manufacturing sector, major intervention will be required in this aspect. A roadmap for achieving energy efficiency and energy conservation will be required. Technology driven solutions can be expected to yield results in case of India and other countries operating at low end of technology. In the short-term, however, quick results can be achieved by implementation of small projects relating to waste heat utilisation and process optimisation. Also, deployment of various technologies and practices in mining, ore beneficiation and pelletisation will lead to use of low grade ores now being discarded and ease the resource constraints.



In the planning for the growth of iron and steel industry, coal as a reductant and energy for smelting the ore will play key role and its availability in quality and quantity ensure the sustenance of this growth in future years. After independence, this sector for our country is termed as a core sector and Government took step for realisation of some major steel projects in public sector. Now, the time has come to conserve the vital inputs for this industry such as coal and iron etc. to ensure their availability for steady growth. In my opinion, coal reserve in our country is not that plenty as it made out. Coal for power generation must be carefully planned. Waste gas from metallurgy industry containing primary ingredient for power generation should be given much importance rather direct burning coal for power generation. In pyrometallurgical process of extraction of metal, carbon in coal is the key element and it picks oxygen blended in the ore and forms waste gas. This waste gas utilisation must be mandatory for power generation, whether sponge iron or ferroalloy route is adopted for metal extraction, the waste gas should be utilised to generate power as a co-product to provide optimum use of our mineral source.

In my long association with metallurgical industry, I have a feeling that we have still to do a lot for improving the base of this industry. Mega projects like steel, ferroalloy and alumina/aluminium plants produce primary metal and the bulk of it is exported to other countries for manufacture of technological products. The value addition and the employment generation in the process are benefited by other countries. It is high time that we should establish downstream industries, utilising the primary metal in mega, medium and small sectors to optimise the benefit for our country or we should stop the export of these non-replenishable minerals and conserve it for future use.

H.P. Mishra, Former Chairman, IPICOL, Bhubaneswar

EFFECT OF RED MUD-LIME FLUX TREATMENT ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF STEELS

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ABSTRACT

The effect of using red mud + CaO mixture as a flux during steel melting has been investigated. Mild steel scrap containing traces of alloying elements was melted under red mud + CaO flux cover in an induction furnace. ASTM keel blocks were cast from both the flux treated and untreated steel melts and then the coupons of the test pieces were hot forged and normalized under identical conditions. The flux treated steels developed finer ferrite grain size and superior mechanical properties compared to those of the untreated steels. Grain boundary precipitates which could not be reliably analyzed , has been detected in TEM in the flux treated samples. In addition, precipitation of grain boundary carbides were also observed in these samples. Complete explanation of these results is not available at this stage.

1. INTRODUCTION

Red mud is a bye product of the bauxite refinery. The principal components in red mud are Fe_2O_3, Al_2O_3, SiO_2 and alkali oxides. However TiO_2 (4-8%) and minor quantities or traces of other oxides such as MnO, Cr_2O_3, CoO, NiO, V_2O_5, Ga_2O_5 and ZrO_2 are also present in red mud generated in Indian plants. Since disposal of red mud is a vexing problem, various attempts are being made from time to time to find gainful applications[1]. In the present investigation, an attempt has been made to utilize red mud as a cover flux along with CaO during steel making. The objective is to observe the likely effect of smelting reduction of some of the oxides on the structure and properties of the steel prepared.

2. EXPERIMENTAL PROCEDURE

500 -600 kg steel scrap was melted in a magnesia lined induction furnace. After usual composition adjustment and aluminium deoxidation, an ASTM keel-block test piece was poured in a resin sand mould. Red mud + CaO (75/25 - ratio) mixture was then added on to the remaining melt. The red mud was thoroughly calcined at 700°C before use. The quantity of the flux was 1 wt% for the first heat and 2 wt% for the second heat. After allowing the molten flux to remain in contact with the melt for five minutes, it was drained off. The last part of the flux was thickened with a proprietary slag coagulator and then skimmed off. The melt was then deoxidized with Fe-Si, Fe-Mn, and Al shots. Another keel-block sample was then poured in a resin sand keel-block mould. The composition of red mud used is given in Table 1. The composition of the steels is given in Table 2.

The keel-block samples were cut and then hot forged. The hot forged rods (20 mm diameter) were normalized from 1223 K. Tensile and impact samples were prepared and tested. The microstructures of the normalized samples were examined first in a light microscope and then in SEM. The ferrite grain size and the volume fraction of pearlite in the samples were also determined. The fracture surfaces of the tensile test pieces were examined in SEM. The experiment was repeated several times. Representative results are presented and discussed below.

Table 1
ANALYSIS OF THE RED MUD (EXCLUDING TRACE ELEMENTS/TRACE COMPONENTS)

Component	Wt%
Al_2O_3	6.26
TiO_2	8.63
Fe_2O_3	7.31
SiO_2	3.84
Na_2O	2.51

Other minor/trace constituent present- V_2O_5, Ga_2O_5, MgO, CaO, MnO, ZrO_2, organic carbon

3. RESULTS AND DISCUSSION

Ferrite grain size and volume % of pearlite in the steels are reported in Table 3. It shows that the ferrite grain size decreased and volume % pearlite increased following red mud flux treatment. On careful examination of the microstructure of the flux treated steel 2b, precipitation of fine discontinuous carbide particles at the grain boundary was also detected in SEM (Fig. 1). The effect of microstructural changes brought about by the flux treatment influenced the mechanical properties of the steels quite appreciably. There was an overall improvement in YS, UTS, percentage elongation and percentage RA after red mud + CaO flux treatment (Table 4). The impact toughness was not affected. But the dimples formed in the fracture surface of the flux treated steels were finer. The fractographs of steels 1a & 1b are compared in Fig. 2. TEM studies on steel 2b confirmed

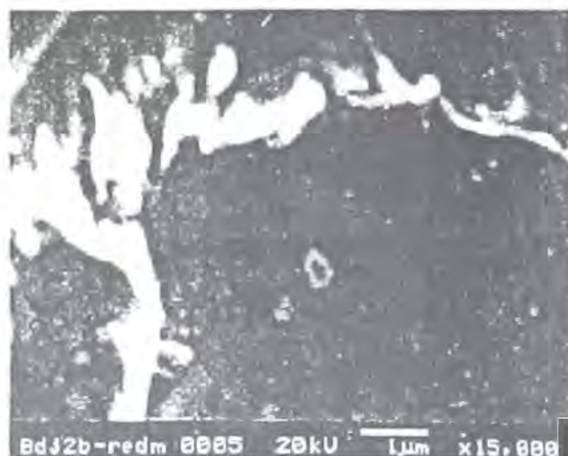
Table 2
CHEMICAL COMPOSITION OF THE STEELS

Elements	Steel 1a	Steel 1b	Steel 2a	Steel 2b
C	0.22	0.25	0.22	0.21
Mn	0.27	0.67	0.59	0.38
Si	0.12	0.26	0.20	0.17
S	0.04	0.05	0.04	0.05
P	0.04	0.04	0.04	0.04
Cr	0.13	0.10	0.51	0.45
Ni	0.09	0.08	0.07	0.07
Mo	0.02	0.03	0.08	0.08
V	0.0003	0.001	0.002	0.001
Cu	0.11	0.11	0.109	0.107
Ti	0.0009	0.001	0.001	0.001
Al	0.015	0.045	0.04	0.09
Remarks	1st heat before flux treatment	Treatment with 1 wt% Red mud +CaO (75/25) mixture	2nd heat before flux treatment	Treatment with 2 wt% Red mud +CaO (75/25) mixture

Table 3

FERRITE GRAIN SIZE AND VOLUME PERCENTAGE PEARLITE OF THE STEELS

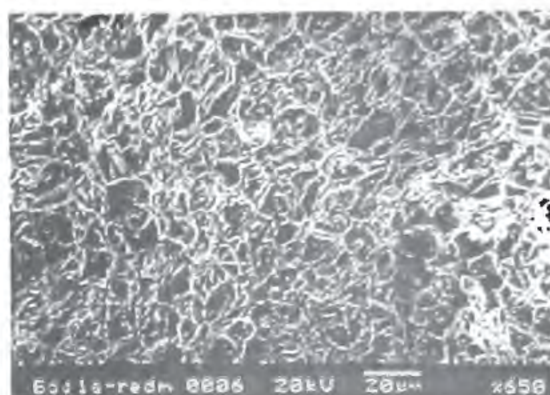
Steel No	Ferrite Grain Size (μm)	Vol. % Pearlite
1a	17.05	40.25
1b	10.50	69.16
2a	16.34	39.23
2b	10.33	73.69



EDX analysis of the grain boundary carbide

	C	Si	Cr	Fe
Element %	8.49	0.39	0.31	90.82
Atom %	30.05	0.58	0.25	69.12

Fig. 1 Precipitation of carbide at the grain boundary in steel 2b.



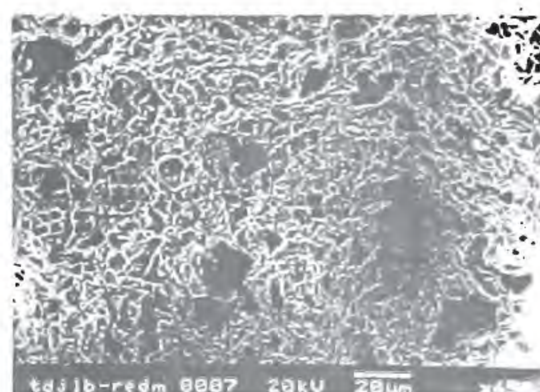


Fig. 2 : SEM tensile fractographs of (a) steel 1a, (b) steel 1b. The dimple size in (b) are finer.

precipitation at grain boundaries, although reliable SAD patterns of the extremely fine precipitates could not be established. TEM photographs of steel 2b are shown in Fig. 3 (a-c).

Table 4

MECHANICAL PROPERTIES OF AS FORGED AND NORMALIZED STEELS

Sample No.	Hardness	YS VHN	UTS MPa	%El MPa	%RA	Room Temp. Impact Toughness Joules
1a	140	35.00	46.21	28.39	62.80	132
1b	197	40.00	58.91	31.80	65.64	130
2a	155	32.00	48.87	23.96	23.08	
2b	202	42.00	59.79	24.72	62.94	-

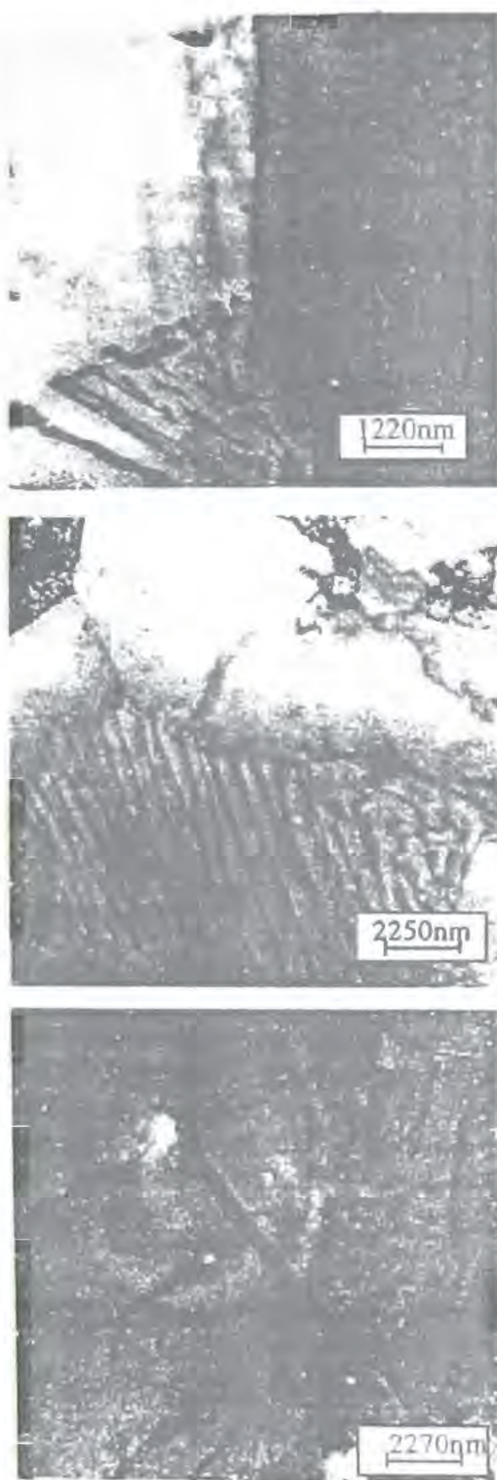


Fig 3 (a-c): TEM photographs of steel 2b showing fine films of precipitates at the grain boundaries

The analysis of the CaO + red mud treated steels as given in Table 2 does not indicate pick up of measurable quantities of Ti, V, Zr from the flux. The recovery or loss of other alloying elements also varied in case of the two steels. Still there was considerable change in the microstructure and mechanical properties after red mud treatment. The result of this investigation therefore presents a perplexing situation. Even if it is argued that higher levels of residual Al in steel 1b and 2b were responsible for better grain refinement in these steels, it can not explain the significant increase in the proportion of pearlite. Another interesting effect observed is the presence of carbide films at the grain boundary (Fig. 1). In a hypoeutectoid steel such grain boundary films of carbide is not expected. The TEM photographs shown in Figs. 3(a-c) indicate precipitation at grain boundaries. All these evidences suggest that trace elements introduced during red mud treatment are responsible for such change. These trace elements presumably produced precipitates which pinned down austenite grain boundaries. They also shifted the eutectoid composition to lower carbon ranges and promoted considerable undercooling dring eutectoid transformation forcing occasional divorced precipitation of carbide at ferrite grain boundaries. It is also suspected that solute atoms segregated at austenite grain boundaries might have acted as kinetic barriers during eutectoid transformation inducing large undercooling. This resulted in both ferrite grain refinement and increase in the pearlite content. However, further investigation is necessary.

4. CONCLUSION

Red mud + CaO flux treatment of liquid steel results in refinement of ferrite grain size, increase in pearlite content and improvement of mechanical properties in as forged and normalised steel.

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Key Words: Ferro-alloys, Raw materials management, Energy conservation

Importance of Raw Materials for Promotion of Ferro-Alloys Industry

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Minerals are the most important raw materials for development of ferro-alloys industry. During a few decades of industrial development, most of our high-grade mineral resources have been mined extensively for internal consumption and export. In this way, most of the high-grade minerals have been exhausted. As these resources are non-replensible in nature, it has been necessary to conserve these valuable natural resources and develop various technologies to process the low-grade and complex ores and minerals to sustain the existing industries in the Country. To make the mineral based industries sustainable, we have to manage the raw materials in a very scientific manner using environmental friendly technology. In this paper emphasised has been given on the importance of ferro-alloys industry in context of iron and steel scenario, the raw material management, some recent developments in ferro-alloys production and proposed R & D programmes for promotion of ferro-alloys industry. The efforts have been made to highlight the developed R&D required to minimise the energy source for the production of ferro-alloys.

Introduction

Ferro-alloys are essential ingredients, used for alloying, refining, deoxidation, desulphurisation in the production of different types of steel and hence ferro-alloys industry forms the backbone of iron and steel in the world. Ferro-alloys industry in India plays a vital role in steel industry to produce various type of steel. The present capacity of ferro-alloys industries is about 5.15 Mt per annum. Our planners envisage that these industries should produce larger qualities of basic alloys, which are required for the growth of steel industries at home as well as to cater to the international market. This is only possible when the management of raw materials and energy required for the production of ferro-alloys is properly done. This paper deals with the utilisation of low-grade ores as well as the wastes produced during processing of raw materials in ferro-alloys industries. The efforts have been made to highlight the developed R&D required to minimise the energy source for the production of ferro-alloys.

Production of ferro-alloys started in India about 62 years ago with setting up of the first ferro-manganese plant by M/S TISCO at Joda, Keonjhar, Odisha. After this, with rapid development of the country's steel industry, the demand for ferro-alloys increased considerably. Number of firms was setup for the production of different types of ferro-alloys. Today, India has adequate capacity for the primary ferro-alloys not only to meet the entire demand of the country but also surplus for the export. As the quality of ferro-alloys effect the steel quality and yield at various stages, they have great impact on the profitability of the steel industries. Hence, value addition is essential by production of ferro-alloys and stainless steel with a view to conserve our mineral ore sources instead of exporting.

The past, present and future of ferro-alloys is linked with the steel production. The planners in India envisaged an ambitious development programe for the iron and steel in the early fifties. They aimed to achieve a target of 20 million tonne of steel within 25 years. Accordingly to make this development possible, ferro-alloys industry was setup in late fifties and early sixties.

In India, by the year 1963, seven plants: 2 in Odisha, 1 in Andhra Pradesh, 2 in Karnataka and 2 in Maharastra were established. These plants have 18 furnaces and have a total installed capacity of approximately 130 MVA monthly for the ferro-manganese. During 1966-67, 10 more furnaces were added with combined capacity of 143 MVA.

During this period, IMFA, IDC, Nav Bharat Ferro-Alloys, Sandur Metal and Ferro Alloy Plant, and Maharashtra Electrosmelt Ltd. came up. In addition to increased capacity for ferro-manganese, they aimed for silicon and chromium alloys. After 1979, three more new plants VIZ OMC charge chrome and Ispat alloys in odisha and VBC ferro-alloys in Andhra Pradesh came up.

In India, most of the Ferro-alloys units have been setup in Andhra Pradesh, Chhattisgarh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha and West Bengal

because of the availability of raw materials. The industry has further spread to North-Eastern region of India. In Meghalaya, a number of small units producing ferro-silicon and ferro-silicon-manganese have come up.

Ferro-alloys may be classified as per the carbon in alloys like low, medium and high carbon ferro-alloys. The most significant and important class of ferro-alloys are low carbon ferro-alloys, which are produced with great difficulty and primarily used in the production of special steels. The other classification is based on the consumption aspects of ferro-alloys. They are (a) based on tonnage alloys and (b) specialty alloys. The tonnage ferro-alloys are of manganese, silicon and chromium. The specialty alloys were developed recently to fulfill the specialised quality requirement of steel technology.

As per Indian Ferro-Alloys Producers Association (IFAPA) at present the total installed capacity of bulk ferro-alloys industry in India is 5.10 million tonnes per annum and noble Ferro-alloys is 50,000 tonnes per annum. The industry is reported to be working at about 60-65% capacity utilisation. The capacity of ferro-alloys of India is given in Table 1. The production of various Ferro-alloys as reported by IFAPA is given in Figs. 1 to 4. Figure 1 shows the production of high carbon ferro-alloys during 2008-09 to 2011-12. The production of low carbon ferro-alloys and noble ferro-alloys has been shown in Figs. 2, 3 & 4 respectively.

Table 1: Capacity of ferro-alloys industries in India (in tonnes per annum)

Ferro-alloy	Installed Capacity
(a) Bulk Ferro-alloys	
(i) Manganese alloys	3160000
(ii)Chrome alloys	1690000
(iii) Ferro-silicon	250000
(b) Noble Ferro-alloys	50000
Total	**5150000**

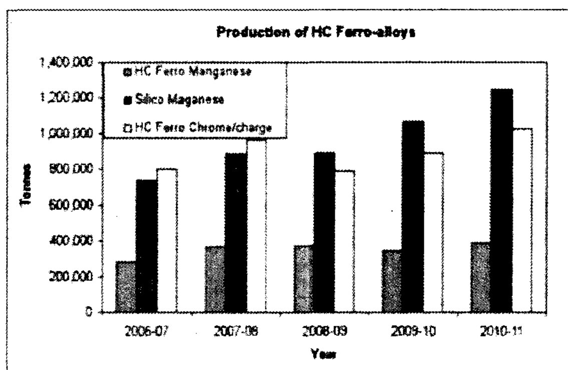


Figure 1: Production of high carbon ferro-alloys during 2008-09 to 2011-12 (Tonnes)

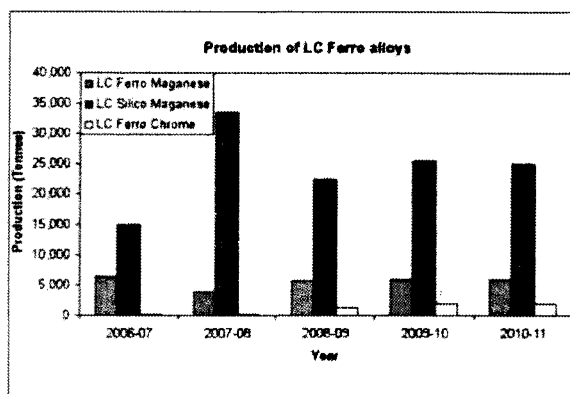


Figure 2: Production of low carbon ferro-alloys during 2008-09 to 2011-12 (Tonnes)

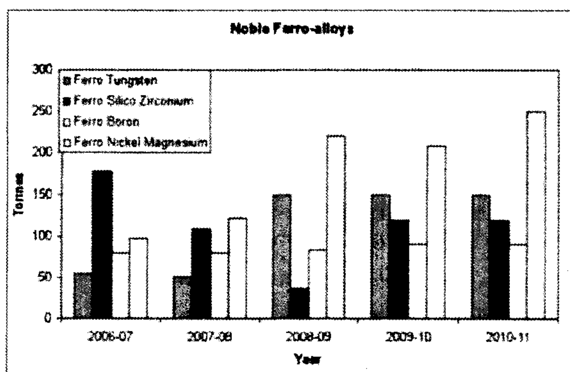


Figure 3: Production of Noble ferro-alloys during 2008-09 to 2011-12 (Tonnes)

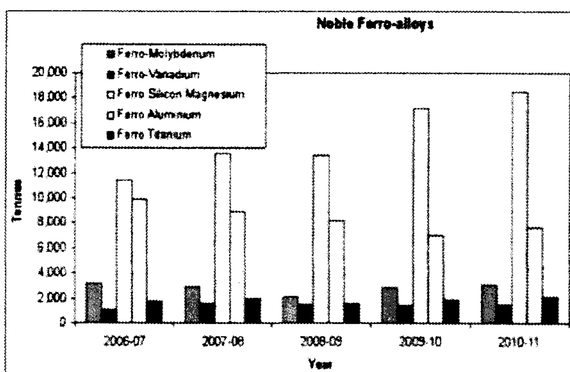


Figure 4: Production of Noble ferro-alloys during 2008-09 to 2011-12 (Tonnes)

Raw Materials for Bulk Ferro-Alloys:

Our Country has reasonable resources of Manganese Ore and Chrome Ore to meet the requirement of Bulk Ferro Alloys Industry, if the policy of conservation of minerals by using beneficiated low-grade ores is followed.

Manganese Ore:

As per the Indian Bureau of Mines Survey Report of April 2010, the total resources are 429,980,000 tonnes out of which about 141,977,000 tonnes is reserve as shown in Table 2. Out of total reserves, BF grade Manganese ore is 49,894,000 tonnes and Ferro-manganese grade is of 12,869,000 tonnes. The present production of Manganese Ore is around 3.00 Million tonnes per annum. Based on the IBM's Report of April 2010, the requirement of Manganese ore for ferro-alloys industry, will be available domestically for 20 years (excluding the inferred reserves). The production of Manganese Ore in India for last five years has been given in Table 4.

[illegible]

Grade	Reserves	Remaining Resources	Total Resources
BF grade	141,977	288,003	429,980
Ferro-Manganese grade	49,894	95,961	145,855
Ferro-Manganese and BF	2,425	13,902	16,327
Ferro-Manganese, Medium & BF mixed	34,541	31,162	65,703
Low ² 25% Mn	1,647	7,505	9,152
Medium	8,694	40,034	48,729
Medium & BF mixed	12,263	32,024	44,287
Mixed	1,763	11,617	13,380
Not Known	2,731	6,702	9,433
Others	7,871	6,053	13,923
Unclassified	7,167	20,216	27,383

Source: Indian Bureau of Mines

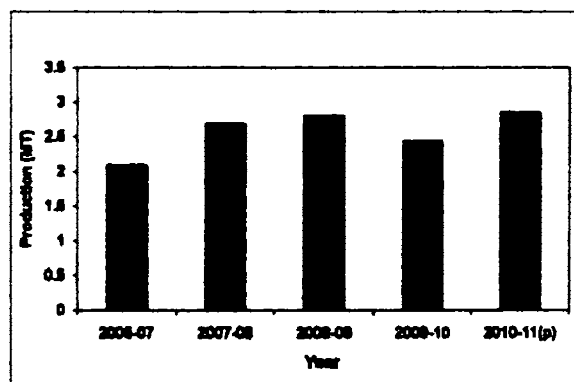


Figure 5. Production of Manganese Ore during 2006-07 to 2010-11

Chrome Ore:

Reserves / Resources:

As per United Nations Framework Classification system (UNFC), total resources of Chromite in the country as on 1.4.2010 are estimated at 203 million tonnes, comprising 54 million tonnes Reserves (26%) and 149 million tonnes remaining resources (74%). Sukinda Valley in the State of Odisha has 97% of Indian Chromite Ore deposits and it has one of the largest Chromite Ore deposits in the World. Minor deposits are scattered over Manipur, Nagaland, Karnataka, Jharkhand, Maharashtra, Tamil Nadu and Andhra Pradesh. Gradewise, Charge-Chrome grade accounts for 35% of the resources, followed by Ferro Chrome grade (19%), Beneficiated grade (17%) and Refractory grade (5%). Low, others, unclassified and not known grades together account for 24%. Gradewise resources of chromite as on 1.4.2010 are given in Figure 6.

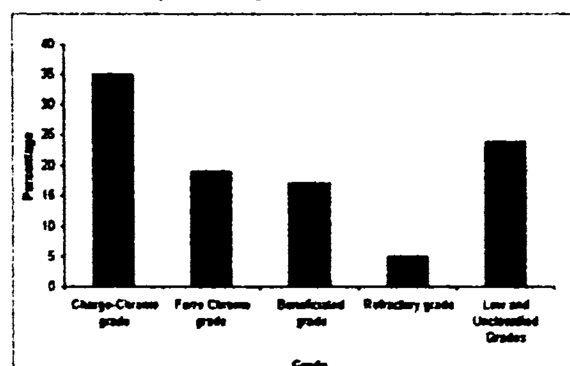


Figure 6: Gradewise resources of Chromite as on April 2010

Based on the Survey report of Indian Bureau of Mines, the requirement of chrome ore will be available domestically for next 15 years (not including inferred) for Ferro Chrome Industry. The Industry has also started to use Chrome Concentrate (Beneficiated product from Low-grade chrome ore). Since the year 2000, the domestic demand of Ferro Alloys is increasing.

Reducing Agents

The high ash and volatile matter contents in the reductants have marked adverse affect on the ferro-alloys produced and furnace operation. The resistivity and reactivity of the reductants also has very significant effect on productivity of the furnaces. The high sulphur and phosphorous contents of the reductants adversely affect the quality of ferro-alloys produced.

- Charcoal is considered as the most ideal reductant in the manufacture of silicon alloys.
- Metallurgical coke from steel plants and other coke making plants along with non-coking coal are used for the production of manganese alloys.
- Imported low ash & low phos. coke along with non-coking low phos. coal and Anthracite coal are used in the production of chrome alloys. In India, coal reserves are about 202 billion tonnes but only about 15% of this is coking coal. Most of the coal are very high in ash and not amenable to known methods of washing because the shale rock is finely

distributed in coal. In the absence of low ash & low phos, coking coal/coke in the Country, production of chrome alloys has to depend on imported coke. The Indian ferro-alloys producers have substituted 50 to 70 per cent of the requirement with low phos. non-coking coal though high in ash and imported low ash anthracite coal from Vietnam and recently from Russia and Ukraine. The production and imports of coal for 2009-10 and 2010-11 are shown in Table 3 and 5 respectively. The production of raw coal in our Country increased from 493 MT to 533 MT during 2008-09 to 2010-11 and our Country imports 69 MT of low ash coal worth of Rs 4154 crores.

Table [illegible]: Production of Raw Coal in India

(In million tonnes)

Year	Production from open-cast mines (% share)	Production from under-ground mines (% share)	Total Production
2008-09	433.79 (88%)	58.97 (12%)	492.76
2009-10	473.52 (89%)	58.52 (11%)	532.04
2010-11	477.84 (89.7%)	54.85 (10.3%)	532.69

Source: Coal Directory of India, 2010-11, Coal Controllers Organisation, Kolkata

Table 4: Imports of Coal for 2009-10 and 2010-11

Country	2009-10		2010-11	
	Qty ('000 t)	Value (Rs.'000)	Qty ('000 t)	Value (Rs.'000)
All Countries	73257	391798228	68918	415494801
Australia	22837	183802972	17273	181449036
Indonesia	32165	115473599	35944	134788133
South Africa	14492	62269478	11214	57272632
USA	1400	13303028	1770	19829296
New Zealand	1059	9976882	795	7703847
Russia	146	1382492	424	4216902
Vietnam	188	1694285	241	2580766
China	45	235500	242	1752587
Philippines	671	2235122	261	801774
Unspecified	-	-	333	1783374
Other Countries	254	1424870	421	3316454

Ferro-alloys Making

The production of ferro-chrome, ferro-manganese and silico-manganese etc. is done in three-phase Submerged Arc Furnace. The Oxides of respective ores of these ores are smelted with carbon. The carbon as reductant comes from coke, coal, char and in some cases wood chips. The fluxes like limestone, dolomite, quartz, bauxite and magnesite are used to slag to desire composition. The raw materials are continuously fed into the Submerged Arc Furnace and hot metals are tapped at regular intervals through tap hole of the furnace. The tapped alloy and slag are separated by de-canting process or by adopting gravity using skimmer blocks. The metal is collected or cast into cast iron pigs. After solidification, the same is crushed, sized and later packed duly in drums or bags with chemical assay to make it ready for dispatch.

In our Country, the total infrastructure and supplies i.e., power supply, transport, and communications, oil supply, coal, ores supply are in control of Government. So, the Ferro-alloys industry is dependent for almost 80% of the total input on supplies from public sector and has no control on cost of these inputs. These costs are much higher as compared to the cost of similar inputs borne by producers in other Countries. For example power costs are 4-5 times higher than the power cost abroad. Hence, with such high input costs, the industry cannot survive to compete in the global market. The Government has to make some policies to assist the industry for production.

In the same time, ferro-alloys industries have to put their main thrust towards modernisation and re-engineering of existing facilities considering application of possible areas of energy conservation since power tariff in India is higher as compared to other Countries. The energy conservation measures can be adopted right from raw materials selection to disposition of final products which can be taken by the ferro-alloys industries is given in Figure.7. The continuous Research and Development in the process and products, energy conservation, utilisation of by-products, pollution control etc. is must to compete in the global market.

Recent Developments

The increase in production of ferro-alloys depends on minimising the energy consumption, for which it is required to (i) use high-grade raw materials (ii) to adopt better furnace design, durable refractory lining and efficient operation (iii) to utilise ferro-alloys scraps and recovery of alloy values from the slag and rejects and (iv) to develop new technology. In recent years, all over the world various R&D work have been taken up in these lines. Further, special types of ferro-alloys like those of refractory metals and rare earths are also been developed.

A new ferro-chrome production route with higher production capacity was developed and commissioned at the Tornio Works of Outokumpu. This new process was specially designed to process soft and friable lumpy ores which was subsequently smelted in a closed electric furnace. In this route,

besides increase in production, there was substantial decrease in energy consumption.

Shcherbin et al. have carried out some laboratory scale studies for producing low carbon ferro-chrome. They have found that the rate is considerable. In a view to manufacture low carbon ferro-chrome, one can use highly calcined lime having a carbon dioxide content of less than 2% unlike the previous practice where this gas content was used to be 3 to 5%. In this manner, it has been possible to produce ferro-chrome having a carbon content of not more than 0.019%. The highly calcined lime can be used for producing medium carbon ferro-chrome.

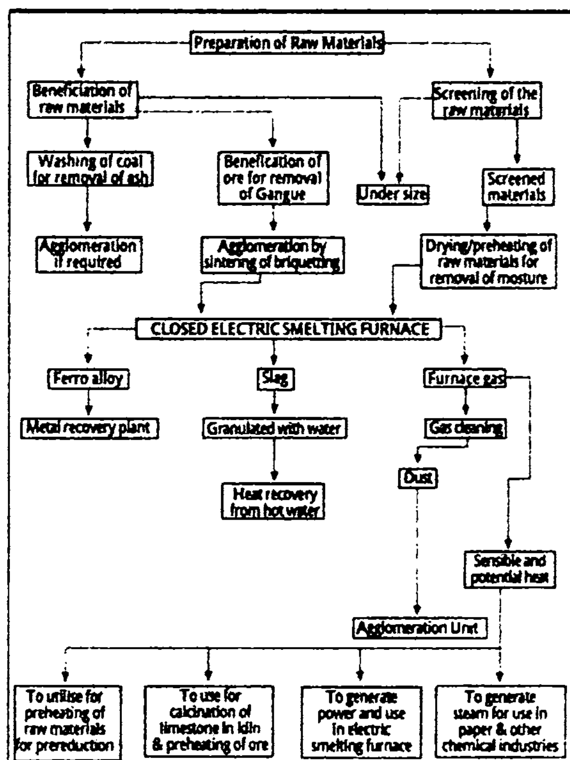


Figure 7: Possible areas of energy conservation in production of Ferro Alloys

Kawasaki Steel Corporation Limited developed a process where reduction of chromium ore in a fluidised bed reactor using a hydrocarbon instead of oil, was carried out. The behaviour of melting, reducing foaming and dripping of chromite in a packed coke bed was examined and the viability of the smelting reduction process was established. However, the pilot scale results have to be examined prior to any commercialisation.

CSIR-Institute of Minerals and Materials Technology, (CSIR-IMMT) Bhubaneswar is involved on smelting reduction of chromite to optimise slag composition to reduce loss of chromium in slag thus improving the chromium recovery in alloy. It has been possible to reduce Cr_2O_3 in slag to a level of 1.3 to 4.0% with 90 to 95% chromium recovery in alloy. Experiments to reduce electrical energy consumption have also been conducted simulating oxy-coal process in induction furnace. With 21/min. oxygen injection on top of the molten slag covered with 25 to 50g coke for duration of 5 to 10 minutes, it has been possible to reduce electrical energy by 30% without affecting chromium content in alloys as well as recovery of chromium.

For producing manganese alloy, preheating and pre-reduction of the smelting furnace charge, has been carried out successfully on bench scale because of the encouraging results, Outokumpu did carry out pilot tests at its metallurgical Research Centre in 1983 in order to optimise the conditions for scaling up the process.

The smelting reduction of manganese ore has been studied in CSIR-IMMT, Bhubaneswar. It is possible to reduce manganese loss in slag to a level of 15.97% with 80% Mn recovery in alloy. The effect of slag basicity on foaming of the slag, reduction of manganese ore and the loss of manganese in slag have been studied in detailed. The effect of temperature on reduction of MnO in slag and the kinetic studies has been made. Efforts have also made to reduce the electrical energy consumption by oxy-coal process in induction furnace. With 51/min. oxygen injection on the top of the molten slag covered with 25 to 50g coke for duration of 2-10 minutes, it has been possible to reduce electrical energy consumption by 30% without affecting manganese content in alloys as well as recovery of manganese.

Recently, a number of developments for producing ferro-nickel from lateritic ores have been made in Japan. Studies on concentrating nickel in lateritic ore up to 50-60% with a low nickel content by segregating process has been reported to be successful. As the process takes place below 950°C, compared to about 1600°C in the conventional smelting process, a 25-30% energy saving is expected on commercial scale.

There is reported production of ferro-nickel 2200 tonnes Ni per month scale at Hyugu Smelter in Japan by rotary kiln and electric furnace. The development made in the areas are (i) improvement in ore sizing, (ii) substitution of heavy oil and anthracite by bituminous coal, pelletisation of rotary kiln dust and (iii) energy saving in electric furnace.

A process for producing ferro-nickel by direct reduction of garnierite ore has been developed by Nippon Yakin Kogyo Corporate Limited, at their Oheyan using a rotary kiln after

pretreatment of raw materials and this crude ferro-nickel can be used as the raw material in the AOD stainless steelmaking process. A simplified mathematical model has been developed for the production of ferro-nickel from lateritic ores by the electrical reduction furnace reduction process (ERF process) and the same has been applied satisfactorily at the plant of LARCO, at Larymna in Greece.

Studies on ferro-nickel making from Sukinda chromite overburden materials have been undertaken by CSIR-IMMT, Bhubaneswar sponsored by M/S TATA Iron & Steel Company Ltd., Jamshedpur. The experiments were carried out to enrich nickel from Sukinda chromite overburden materials by reduction roasting in pan sintering unit followed by magnetic separation. Further experiments were carried out on smelting of nickel concentrate to make ferro-nickel. Trial runs were carried out on 50kg scale using sintering pot grate furnace of 400x400x430 mm cross section with 400 mm bed height and 500 WG suction pressure below the grate bars. It has been possible to get a nickel rich concentrate containing up to 1.4% Ni from the feed containing 0.74% Ni by using the above process. When this concentrate was subjected to smelting studies, it was possible to obtain ferro-nickel containing up to 4.1% Ni with 90% metal recovery.

In recent years, with the development of plasma generating system and the design and fabrication of large size plasma furnaces, various efforts are being made to produce metals and alloys by using such facilities. Plasma Furnaces are being used for direct reduction of iron oxide, chromite, manganese oxide, ilmenite etc. to produce the metals and their alloys. Plasma systems are also used for dissociating metal halides, in slag refining as well as various gas phase reactions.

The installation and commissioning of a (500lb) 220 KVA DC transferred arc plasma furnace at the Mineral Resources Research Centre of University of Minnesota. The furnace is based on a hollow electrode designed with a 10cm graphite cathode and tilting lip for sample pouring.

In early seventies, SKF Steel started a long range research and development programme to produce metals and alloys by applying plasma technology. As a result of these efforts, it has been possible to develop commercial processes for producing iron, steel and ferro-alloys. Simultaneously, they have also developed plasma generators in the range of 1-10MW.

In New Zealand, plant studies have been made to produce ferro-alloys by plasma as alternative to fossil fuels and electrical energy. These include the production of ferro-vanadium from New Zealand Steelworks slag; treatment of steel plant dusts, ferro-silicon, enrichment of titanium value in ilmenite etc. The council for Mineral Technology has embarked on a programme to produce ferro-titanium containing 30-40% Ti, and also Ti-Al-Fe alloy from a high titanium slag by using DC transferred arc plasma system.

Various R&D activities on titanium have been carried out at CSIR-IMMT, Bhubaneswar. The studies on recovery of ilmenite and sillimanite from beach sand concentrate has been sponsored by M/S TATA Steel, Jamshedpur. Another beneficiation studies on beach sands of Srikakulam district, Andhra Pradesh has been sponsored by M/s Trimex Industries Ltd., Hyderabad. A number of other projects on plasma smelting of illimenite has been undertaken. A detailed study was conducted on the separation of titanium rich slag and iron from pre-reduced consumption. The studies were conducted with static bed plasma smelting reactor as well as moving bed plasma smelting reactor, which was designed and fabricated based on the static bed data.

A detailed report was submitted to M/S Indian Rare Earth Ltd. Chattrapur. The results clearly indicate that by varying various plasma processing parameters, it is possible to minimise the energy consumption significantly. The degree of metallisation also plays an important role in minimising energy consumption and improving slag quality.

The proposed R&D programmes

The Proposed R&D Programmes can be directed into the following areas:

1. Recovery of potential and sensible heats in off gas by implementation of closed Submerged Arc Furnace.
2. Decrease in slag production which can save about 60-70 units of power per tonne of product.
3. Utilization of tapped molten ferro-alloy directly in steel making to conserve about 10-15% heat equivalent to electrical energy inputs in steelmaking.
4. Application of computer control system for process control and raw materials handling system which helps to bring down 5-10% of specific energy consumption.

5. Implementation in furnace design and electrical parameters which help to save the electrical losses in the system and reduces the specific consumption.
6. Agglomeration of ore fines to utilise the fine ores
7. Beneficiation of low-grade ores.
8. Beneficiation of high ash coal which can be used as reductant in production of ferro-alloys.
9. Utilisation of plasma smelting for direct feed in form of fines of ores and reductant.
10. Refining of Ferro-alloys outside the furnace.
11. Development of new Ferro-alloys.
12. To find out the cheaper sources of power generation for captive use like solar energy, wind energy, hydel energy or captive power plant based on DG sets/ gas turbine/thermal power station.

Conclusions

During 1950 to 1970, our industrial development was in its infancy to meet our foreign exchange requirement. Iron ore, chrome ore etc. were exported. In the subsequent period the ferro-alloys and sponge iron industries were setup to add value. In this century, the metal price in the international market has gone up substantially and therefore, the conversion of semi product to finished product is extremely important from national point of view.

The production of Ferro-alloys in larger quantities of basic ferro-alloys which are required for the growth of steel industries at home as well as to cater to the international market is only possible by proper management of raw materials and energy required for the production of ferro-alloys. The mineral like chrome ore and nickel ore are non-renewable assets and our Country has got limited reserve. Therefore, it is very important on our part to make judicious use keeping in view our long term requirement. For this purpose, chrome ore and chrome alloy export to be limited and all efforts should be made to convert charge chrome to stainless steel and special steel to meet domestic and export need.

Beneficiation plants to upgrade our medium and low grade chrome ore and nickel containing chrome ore overburden should be installed for charge chrome and ferro-nickel production. The charge chrome and ferro-nickel are basic input for stainless production.

Value added products (Engineering and other technological items) are to be produced for meeting domestic demand and export with a view to conserve our mineral resources. In the past, we have already suggested to Govt. of Odisha that processing of raw materials which are being wasted during mining are to be scientifically utilised to produce value added product. This will be promoted by a company as an auxiliary of OMC/IPICOL entitled "National Innovative Mining and Metal Limited" to look after the promotional effort establishing pilot demonstration and commercial plant in our State. These valuable raw materials can provide the base for manufacturing of Fe-V, Fe-Ti, Fe-Ni etc. which our Country is importing for production of special steels. We understand this is under consideration by Govt. of Odisha.

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- *Source: Iron and Steel Review, Vol. 56, No. 11, April 2013, pp120-131.*

CHAPATER 4

Development of Sponge Iron Based Industries

Sponge Iron - Problems & Solutions



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Introduction

Sponge iron is reduced form of iron ore and has an iron content of 83 - 92%. It is a substitute of steel scrap for steelmaking through the secondary route i.e. direct reduction/electric arc furnace. This also replaces ferrous scrap as a coolant in LD converter. The value of DRI is measured by comparing its cost and properties with those of scrap. It has low sulphur content and has the advantage to use non-coking coal for reduction and fuel purpose.

For better melting results, the criteria for selection of sponge iron are -

- High total iron content;
- Amenable to appropriate reduction;
- Low gangue, sulphur and phosphorus content;
- Suitable size, range and shape.

The advantages of using sponge iron in electric arc/induction furnace in the charge mix are as follows.

- DRI permits automatic continuous batch charging.
- It helps create a foamy slag - provides lower electricity consumption, faster melting time, decreased electrode consumption, longer refractory life and enhanced steel quality.
- The chemical composition of DRI is known exactly and is uniform.
- It contains very low level of undesirable metallic impurities.
- Use of DRI permits dilution with low cost scrap.
- Less noise occurs during meltdown with DRI than scrap.
- It does not require desulphurising and dephosphorising process in electric arc/induction furnace.

Review of Direct Reduction Processes

Essence of DR Process

Any DR process features 4 distinct steps.

- The availability of reducing agents, e.g. solid carbon, carbon monoxide, hydrogen.
- Heating of the burden to reaction temperature, and supply of reductant for the reduction process.
- Ore reduction by providing adequate time of contact between the iron ores and other reductant.
- Cooling and discharging of the directly reduced ores, evaluation of the waste gases following completion of reduction.

Classification of DR Processes

A DR process may be classified by the type of reductant it uses - solid or gaseous. It may be identified according to the furnace it utilises - rotary kiln, shaft furnace, retort reactor or fluidised bed reactor. Generally, DR processes are classified into the following four types:

- Rotary kiln process on the basis of solid carbon.
- Shaft furnace processes on the basis of reduction gases produced from solid carbon, or produced by cracking natural gas or fuel oil.
- Retort process on the basis of reduction gas produced by cracking natural gas or on the basis of solid carbon.
- Fluidised bed process on the basis of reduction gas produced by cracking natural gas or fuel oil.

Process Description

HYL Process

The process has been developed to use economically reduction agent other than natural gas, such as reforming of naptha or ther light hydrocarbons, gasification of coal and oil and a completely new technique of use of coke oven gas without any reforming facilities.

Due to the static bed characteristics of the direct reduction process, fines generation is the lowest, allowing the direct charging of such fines and externally heated by the combustion of the process 'tail gas' used as fuel to recuperate its remaining heating value. The gas is passed through a desulphurising unit at the entry of the plant.

Apart from naptha reforming, the reducing gas can also be produced by coal gasification and partial oxidation of fuel oil.

The reducing section of an HYL plant consists of a set of four reactors, three of which are in line and the fourth in charging - discharging operation. The reduction of the ore is performed in two stages and third stage for cooling and carburisation, each stage last about 3 hours. The first one is a heating and initial reduction, for the materials just charged, where the first part of reduction take place The second stage, where the main reduction occurs, and the third stage, where the final points of metallisation are achieved and also deposition of carbon. Carbon deposits during the cooling stage and mainly during the period when the temperature of the product passes through a certain 'carburisation band' occurring in the neighbourhood of 550°C. At such temperature, carbon deposits as Fe3C, forming a 'cementite shell' which among other advantage, protects the product against reoxidation. In the HYL sponge iron, over 95% is a cementite carbon and mainly concentrate in the external shell. About 80% of the carbon deposition is concentrates in an external shell of about 2 mm. The reduced material can be directly charged in the electric furnace, so, no screening operation are required thus eliminating the cost of screening and briquetting.

In the HYL process, a reducing gas rich in hydrogen and carbon monoxide is used, obtained by several procedures one of which is the catalytic reforming of natural gas, which is mixed with water vapour before entering the reformer unit. Though most of the HYL plants operate with natural gas, other feedstock for steam reforming are propane, butane and naptha.

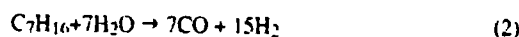
Steam reforming for these inputs may be represented by the following two chemical equations.

For natural gas



$$CH_4 + H_2O \rightarrow CO + 3H_4 \quad (1)$$

For naptha



$$C_7H_{16} + 7H_2O \rightarrow 7CO + 15H_2 \quad (2)$$

These reactions are endothermic and so, require heat and a nickel base catalyst.

Apart from naptha reforming, the reducing gas can also be produced by coal gasification and partial oxidation of fuel oil.

Metallisation and productivity

The metallisation is a function of time of contact between gas and iron ore, the metallisation level can be varied at will by controlling the cycle time. An HYL plant can operate satisfactorily within limits of 83 to 94%. The productivity of an HYL plant is directly related to the metallisation. A decrease in metallisation is accomplished by a decrease in cycle time, which reflects in an increase in productivity. Such metallisation decrease is beneficial if carbon deposition can be increased so as to produce a 'balanced' sponge iron, where the carbon content compensate for the additional FeO in the product.

The increase in productivity thus obtained represents a decrease in operating costs fixed and variable in the same percentage of the production increase, since the plant will remain operating at the same total gas composition same electricity, same man power, same financial costs, etc.

Some of the salient features of HYL technologies are as follows:

- Plant capacities 100,000 to 700,000 tpy in a single module or multimodules can be set up.
- Reducing gas can come from reformation of natural gas or any light hydrocarbon by gasification of coal or oil or by different use of coke oven gas.
- Metallisation and carbon are accurately controlled and can be combined to give a balanced product.
- Energy requirement are lower than 3G Cal/tonne.
- A wide range of iron ores can be used as feedstock, as pellets, lump ore or any combination thereof.
- Fines generation is kept to minimum. Such fines can be changed directly to the furnace without screening or briquetting.
- HYL product is stable, even if stored in open space. Any means of transportation is acceptable.
- Outstanding characteristics of steelmaking. The boiling action created by the formation of gases increases the thermal efficiency, which reflects in cost savings and increase in productivity.

Midrex Process

The Midrex technique produces 92% to 99% metallised material from cold industrial oxide pellets as they pass down a shaft furnace in a counter flow of heated reformed gas. The reforming natural gas has a H_2/CO ratio of 1.6 and the

temperature is 900°C, in furnace pressure of the counter current shaft furnace is 100 kilopascals and the energy necessary for reduction is 10.5 giga-jules / tonne - DRI. Part of the exhaust is mixed with natural gas and reformed, and the remainder is used as the fuel for the reformer furnace. In the HYL-III process, the H_2/CO of the reformed gas is 3, the temperature is 930°C, the in furnace pressure of the counter current shaft furnace is 450 kilopascals and the energy necessary for reduction is basically the same in the Midrex process. In both processes, higher furnace temperature result in higher productivity because the metal is reduced by endothermic reaction.

However, an excessive furnace temperature will cause the pellets and lump ore to melt during reduction. The maximum reducing rate is about 95% and the carbon content is limited to about 2.5%.

The large specific area of the active surface of spongy DRI makes it sensitive to reoxidation and ignition when it comes into contact with air and water, specially sea water. Handling and transformation were therefore difficult and potentially hazardous. To overcome this difficulty, a hot briquetting facility to minimise the specific area by compaction was developed and has been installed in the lower part of the counter current shaft furnace. This had resulted in producing hit briquetted iron (HBI) has minimised the risk of ignition and substantially reduced reooxidation making handling and transportation of DRI much easier, and enabled DRI to be used as a substitute for scrap in steelmaking by the electric furnace.

SL/RN Process

The original SL process was centred around a rotating refractory lined cylinder, slightly inclined to the horizontal so that ore and solid reductant feed in one end will travel by gravity, through several heating zones and exit from the other end. The modification in RN process added a system of burners positioned along the full length of the cylinder, the fuel inputs to these burners may be controlled and varied so that a desired temperature profile in side the kiln may be maintained longitudinally. Together, these systems make up the SL/RN process.

The flexibility in the use of wide range of carbonaceous material is one of the important advantages of this process. Supplementary fuels such as natural gas, fuel oil may also be used. Limestone and dolimite may be included with the input material as part of the charge to take case of the sulphur of the reductant.

The kiln temperature is maintained around 1050°C with residence time from 2 to 5 hours. The residence time and productivity depends greatly on the desired degree of metallisation and the characteristics of the ore and coal. The reducibility of ore and its degradation tendency are important factors but coal reactivity and ash fusion temperature are far more essential.

After the processed material are discharged from the kiln and cooled, the metallic product is separated from the coal char and flux by screening. The char is recycled so that the kiln at all times has a large excess of reducing agent. Sponge iron, 92 to 94% metallisation is produced by this process. The energy requirements has been claimed to be low 14 million BTU/tonne of iron produced.

The SL/RN processes may be characterised by the two types of plant. Long rotary kiln, with iron ore charged in a cold condition, heating and reduction taking place in the kiln. Short rotary kiln with traveling grate place ahead of the kiln where the ore is preheated by the waste gas.

Sponge Iron Industries in India

India has emerged as the world's largest producer of sponge iron after Venezuela. The growth of sponge iron units specifically during the last part of nineties is substantial in terms of capacity and production. Installed capacity of sponge iron units increased and stood at around 36 million tonnes. After Brazil, India is the only country which has both gas-based and coal-based plants. Besides, almost all sponge ironmaking processes like SL/RN, ACCAR, CODIR, KRUPP, TDR, HyL, MIDREX are in operation in India.





Major Problems with Sponge Iron Plants

Following are the major problems generally encountered in sponge iron plants.

Raw Material: DRI technologies are very sensitive to the quality of raw materials like iron ore and coal. For rotary kilns, disintegration behaviour of iron ore is very important in evaluating lump iron ores. Degradation during and after reduction should be low. If this is not low fines content of the product is high. DRI of less than 3 mm are not preferred. Since no melting or refining occurs all other impurities in the oxide feed get concentrated in the final product necessitating the use of ore with high iron content preferably greater than 64%. Coal should be totally non-coking in nature, as the coking quality leads to agglomeration of charge, reducing reduction process and material flow in the kiln. With high ash content of coal, a significant portion of kiln volume is occupied by inert material and thus affecting the productivity. Ideal ash content is 20-24% although coal with 35% ash is being used in commercial operation. Coal sizing becomes difficult during rainy seasons.

Ring formation in rotary kiln:- Formation of ring or accretion is due to deposition of low melting complex compounds on the refractory wall of the kiln which increases in thickness with fine and ultimately takes the shape of a circular ring. The main reason is the formation of low melting complex compounds like wustite, fayalite in FeO-SiO_2-Al_2O_3 system or iron-magnesium silicate, spinels, etc. in CaO-MgO-FeO-SiC_2-Al_2O_3 system. Agglomeration of fines nearer to charge end, sintering of sponge iron due to excessive temperature is also responsible for some accretions. Temperature difference between solid and gas should not exceed 100°C in order to minimise concentration of heat on refractory wall or on the solid bed surface and thereby preventing materials fusing and sticking together or on the refractory wall. Use of higher reactivity coal can minimise this to large extent since kiln can be operated at relatively lower temperature.

Magnetic separation of finished product from non-magnetic generally does not perform well. About 2 - 3% char is mixed with the prime product.

In gas-based sponge iron plants following problems are encountered:

i. Fluctuating compositions of natural gas.
ii. Channeling of the gas flowing through the packed bed in shaft furnace.
iii. Sticking together of the materials.
iv. Contamination of reformer catalyst especially with high sulphur containing feed.
v. Product is pyrophoric and needs briquetting.

Scopes for Process Improvements

Coal-based sponge iron process has the main drawback of higher energy consumption compared to gas based process where a major portion of waste energy is recycled in the process itself. Following measures can be taken for improving thermal efficiency and other process parameters:

i. By enriching secondary air with oxygen energy consumption can be reduced.
ii. Injection of submerged air reduces the length of preheating zone in rotary kiln.
iii. Use of alternative reductants like charcoal, lignite, middlings from coal washeries.
iv. Use of coal gasification and of gasified coal in shaft furnaces. By means of coal gasification virtually all types of non-coking coal can be utilised for direct reduction process.
v. Use of coal gasification and of gasified coal in shaft furnaces. By means of coal gasification, virtually all types of non-coking coal can be utilised for DRI process.
vi. Utilisation of waste heat for power generation. About 25 GCal of heat/hour is lost in a rotary kiln of 0.1 million TPA capacity.
vii. Proper utilisation of iron ore fines wasted during crushing and sizing by slinging ore fines (3-6 mm) into the kiln from the discharge end.

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PRODUCTION OF PIG IRON FROM NALCO REDMUD BY APPLICATION OF PLASMA SMELTING TECHNOLOGY

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Keywords: Bauxite[1], Redmud[2], Plasma Smelting[3], Pig Iron[4], Slag Cement[5]

Abstract

Red Mud, a by-product generated from the caustic leaching of bauxite to produce alumina in the Bayer Process, causes serious environmental problems and is considered as a hazardous industrial waste. A novel process has been developed for production of Pig Iron from NALCO Red Mud by employing Plasma Smelting Technology. Red Mud containing 15-40% Fe_2O_3 was subjected to Thermal Plasma Smelting by use of Extended Arc Plasma Reactor at a temperature of 1600°C for a period of 30 minutes and high quality Pig Iron was produced. Effect of various process parameters like basicity, amount of reductant, plasmagen gas, input electric power and reduction time for recovery of Pig Iron has been studied and optimized. Basicity of 0.3, reduction time of 25 minutes at 12.5 kW power was found to be optimum for maximum recovery of pig iron (70%) from Red Mud in 1kg scale.

Introduction

During digestion of bauxite with caustic soda employing Bayer Process, Red Mud, a hazardous waste material is generated at the rate of two tons of Red Mud per one ton of alumina. NALCO, a Navaratna Company under Government of India, has set up Asia's largest integrated Alumina- Aluminum complex in the state of Odisha, India and produces 15,75,000 MT of alumina per annum. In the process about 31,50,000 MT of Red Mud is generated which is preserved in a nearby pond specifically made for the purpose which contains around 30-50 % iron.

One among the top ten alumina refineries in the world, NALCO's energy efficient alumina refinery utilizes time tested Bayer's process technology of atmospheric pressure digestion at lower temperature.

Utilization of Red Mud for production of cement, tiles, bricks and blocks etc has been tried by many researchers. However these efforts have resulted in partial utilization of Red Mud and the problem of bulk utilization of Red Mud still remains a challenge. Since Iron is a major constituent of Red Mud, it was thought prudent to extract iron values in the form of Pig Iron utilizing the novel Plasma Smelting Technology. By employing this technology, techno-economic feasibility for bulk utilization of Red Mud can be established.

Raw Materials

The raw materials used for the present work are NALCO Red Mud, Limestone , Quartz and Fluorspar. The chemical analysis of these raw materials are presented in Table-1 and Table-2. The chief constitute of Graphite is carbon of 99%.

Table-1 : Chemical Analysis of NALCO Red Mud (wt%)

Red Mud	Fe_2O_3	SiO_2	TiO_2	Al_2O_3	Na_2O	K_2O	LOI	MgO	CaO
Batch-I	53.6	18.9	2.20	4.88	8.29	-	9.30	0.21	0.54
Batch-II	47.60	4.10	5.60	14.36	-	-	12.51	0.27	0.62
Batch-III	48.6	2.25	7.26	16.68	-	-	12.80	0.31	0.67

Table-2: Chemical Analysis of Limestone, Quartz and Fluorspar

Constituents	Wt %		
	Limestone	Quartz	Fluorspar
CaO	45.59	2.50	60.00
SiO_2	4.04	96.50	-
MgO	7.10	0.50	-
Al_2O_3	0.26	-	-
CaF_2	-	-	40.00
Other Oxides	1-5	-	-

Experimental

Experimental Set up:

Schematic diagram of 50kW DC Plasma reactor is shown in Fig.1. It is a pot type of rector where two graphite electrodes are arranged in the vertical configuration. The graphite crucible is used as the hearth of the reactor and is connected to the bottom graphite anode. The crucible assembly constitutes the anode. The top graphite electrode known as cathode is having an axial hole to pass the plasma forming gas. The bottom electrode and the crucible are kept fixed. The formation and stabilization of the plasma arc is done by the movement of the top electrode, with simultaneous application of power supply which is actuated by a rack and pinion mechanism. The hearth is thermally insulated by the bubble alumina in a mild steel casing. Graphite spout is connected in the hearth for tapping of both metal and slag. The water cooling system is provided at the end of the top and bottom electrode to avoid the over heating of electrical terminals. A graphite lid is provided with ceramic insulation to promote free travel of the electrode without electrically shorting the body. The lid is thermally insulated with magnesia and opened for the exhaust gases. The electrical power to the plasma reactor is supplied by a DC 50 kW power source

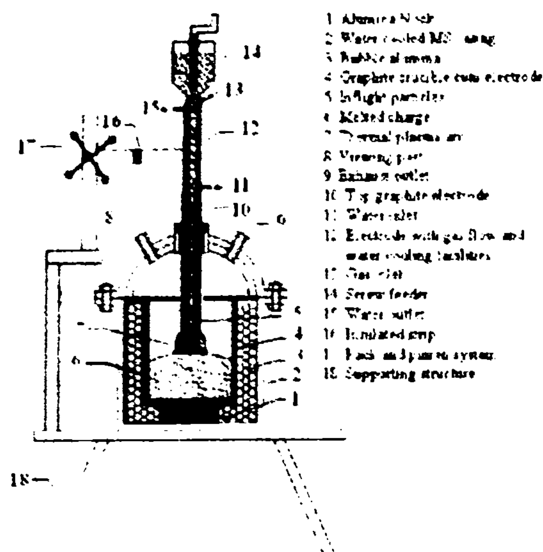


Fig.1 Schematic diagram of indigenously developed extended arc plasma reactor

Plasma Smelting of Red Mud:

Initially Red Mud, coke and dolomite / limestone/ fluorspar (flux) powder of required composition were thoroughly mixed and charged inside the graphite crucible. Argon gas was used as plasmagen gas and was passed through the top electrode at a rate of 1.0 LPM. The arc was struck and the current of 250 amperes was maintained with an arc voltage of about 60 volts. The plasma arc was continued for 20 to 30 minutes to complete the chemical reaction. The temperature of the molten bath was measured by using Minolta Optical Pyrometer. At the end of the smelting, the tap hole was opened and the molten pig iron and slag were allowed to pour in to the graphite mould. The experimental conditions are furnished in Table-3.

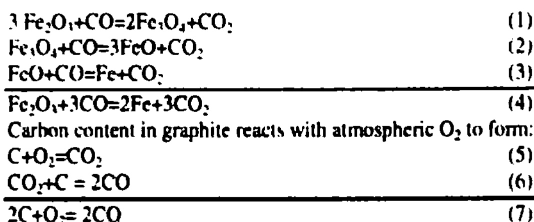
Table-3 Experimental conditions optimised

EXPT. NO.	Raw material	Current (I)	Volt-age (v)	Time (m)	% of metal
1 (Red Mud + 11% Graphite + 5% Quartz)	Redmud=200gms Graphite=20gms Quartz=10gm	250	50	11	32.61
2 (Red Mud + 11% Graphite + 10% Limestone + Quartz) [Basicity 0.15]	Redmud=1kg Graphite=110gm Quartz=40gm Lime stone=100gm	250	50	25	67
3 (Red Mud + Graphite + Fluorspar) Fulorspar is added before tapping [Basicity 0.23]	Redmud=1kg Graphite=110gms Quartz=50gm Flourspar=94gm	250	50	25	69.26
4 (Red Mud + Graphite + Flurospar + Limestone) Flurospar is added before tapping [Basicity 0.33]	Redmud=1kg Graphite=110gms Quartz=50gm Lime stone=50gm Flourspar=47gm	250	50	25	60

Results and Discussions

The red mud along with graphite and flux (Limestone/ Flourspar) were smelted in 35kW extended arc plasma reactor. The main aim and objectives of the work was to find out higher recovery of Pig Iron. To achieve this, the process parameters like basicity and reduction time were studied.

The probable chemical reactions occurring during Fe_2O_3 reduction are the following:



$3Fe_2O_3+CO=2Fe_3O_4+CO_2$ (1)

$Fe_3O_4+CO=3FeO+CO_2$ (2)

$FeO+CO=Fe+CO_2$ (3)

$Fe_2O_3+3CO=2Fe+3CO_2$ (4)

Carbon content in graphite reacts with atmospheric O_2 to form:

$C+O_2=CO_2$ (5)

$CO_2+C = 2CO$ (6)

$2C+O_2= 2CO$ (7)

CO is most stable at above 1000°C. It is a good reducing agent and reduces Fe_2O_3.

In plasma furnace, CO reacts with Fe_2O_3. The reaction steps are as follows:-



$Fe_2O_3+CO=Fe_3O_4+CO_2$ (8)

$Fe_3O_4+CO=FeO+CO_2$ (9)

$FeO+CO=Fe+CO_2$ (10)

However some direct reduction of FeO by solid carbon may also occur according to the reaction (11). All the equations except (11) are exothermic.



$FeO + C = Fe + CO$ (11)

The experimental parameters like effect of basicity, reductant and reduction time have been studied and a typical metal and slag analysis are given in Table 4 and Table 5.

Table-5 Typical analysis of Pig Iron

Basicity	Test Parameters (wt%)				
	Fe	C	S	P	Si
0.25	94.95	4.10	0.051	0.198	0.07

Table-6 Slag Analysis

Test Parameters (wt%)						
Fe(Metal)	FeO	Al_2O_3	SiO_2	CaO	Na_2O	MgO
5.64	5.03	41.82	13.49	20.29	3.94	5.80

The Effect of Basicity on the Recovery of Pig Iron:

Basicty plays an important role in the production of Pig Iron from Red Mud. The basicity ranging from 0.07 to 1.50 has been studied. It is observed that the maximum recovery of 71.10% achieved with the basicity of 0.25. With further increase of the basicity, the metal recovery decreases (Table-7). This may be due to the fact that presence of alumina makes the slag more viscous. This is substantiated by the metallographic and EDS studies (Fig. 5).

Table-7 Effect of Basicity [Red Mud (RM),Limestone(LS), Graphite(G), Quartz (Q), Dolomite (D)]

Sl No	Raw Materials	Basicity	Metal Recovery (%)
1	RM=350g,G=11%, $CaCO_3$=6%,MS=6%, Q=5%	0.07	62.00
2	RM=350g,G=11%, LS=10%, Q=5%	0.20	65.64
3	RM=350g,G=11%, Q=5%, F=10%	0.23	70.00
4	RM=350g,G=11%, Q=5%, D=12%	0.25	71.10
5	RM=350g,G=11%, Q=5%, D=14%	0.29	62.60
6	RM=350g,G=11%, Q=5%, D=16%	0.32	60.00
7	RM=350g,G=11%, Q=5%, LS=87g	0.40	61.50
8	RM=350g,G=11%, Q=5%, LS=110g	0.50	50.40
9	RM=350g,G=11%, Q=5%, LS=229g	1.00	55.00
10	RM=350g,G=11%, Q=5%, D=795g	1.50	40.70

The Effect of Reductant on the Recovery of Pig Iron:

The effect of reductant on the recovery of Pig Iron was studied in the range of 9 to 14% of the charge mix. In this case graphite is acting as the reductant. The results are shown in Table-8. From the results obtained, it is observed that the recovery of metal is increasing with increasing the amount of reductant from 9 to 11% and thereafter, a decrease in trend is observed. The reasons are not clear and needs further in-depth investigation.

Table-8 Effect of Reductant (graphite)
[Experimental Conditions : time= 15min, Power= 12.5 kW and Basicity=0.2]:

Sl. No	Material Charged	Reductant (%)	Metal Weight (g)	Metal Recovery (%)
1	RM=350g, LS=10.0%, Q=5%	9.00	64.50	55.60
2	RM=350g, LS=10.0%, Q=5%	10.00	69.50	60.00
3	RM=350g, LS=10.0%, Q=5%	11.00	76.00	65.54
4	RM=350g, LS=10.0%, Q=5%	12.00	71.00	61.24
5	RM=350g, LS=10.0%, Q=5%	13.00	60.00	51.72
6	RM=350g, LS=10.0%, Q=5%	14.00	49.00	42.20

The Effect of Reduction time on the Recovery of Pig Iron:

The recovery of Pig Iron production depends on the reduction time. The time range from 11 to 17 min have been studied. The results are shown in the Table-9. It is observed that there is increase in the recovery of Pig Iron up to 15 min and thereafter it decreases. This may be due to evaporation of metal values during prolonged smelting operation period. This may be due to the reverse reaction of iron to form complex failite slag. Further investigation in this line is being carried out.

Table-9 : Effect of Time: [Power 12.5 kW and Basicity= 0.2]

Sl No	Material Charged	Time (min)	Metal	
			Wt.(g)	(% Recovery)
1	RM=350g LS=10.0%, G= 11.0%, Q=5%	11	37.00	31.89
2	RM=350g LS=10.0%, G= 11.0%, Q=5%	12.00	35.00	30.17
3	RM=350g LS=10.0%, G= 11.0%, Q=5%	13.00	35.00	30.17
4	RM=350g LS=10.0%, G= 11.0%, Q=5%	14.00	60.50	52.15
5	RM=350g LS=10.0%, G= 11.0%, Q=5%	15.00	76.00	65.51
6	RM=350g LS=10.0%, G= 11.0%, Q=5%	16.00	61.00	52.58
7	RM=350g LS=10.0%, G= 11.0%, Q=5%	17.00	60.00	51.70

Statistical Design of Experiments:

The experimental parameters like basicity, reductant, time and power have been optimised by statistical design of experiments and extrapolation of results which indicates that basicity of 0.3, reduction time of 25 minutes at 12.5 kW power was found to be optimum for maximum recovery of pig iron (70%) from Red Mud in 1kg scale.

Process Flow Sheet:

Thermal Plasma Technology offers a unique process for the production of Pig Iron from Red Mud- an industrial waste from Alumina Refineries. By employing this technology, a process flow sheet has been developed for extraction of Pig Iron from NALCO Red Mud which is shown in Fig. 2.

The appropriate quantities of raw materials viz. Red Mud, reductant and flux are mixed properly in a dry ball mill and then the charge mix was subjected to Thermal Plasma Treatment. The charge mix was smelted in the Thermal Plasma Reactor and the metal and slag were tapped separately. The tapped metal can be

alloyed with Fe-Si, Mg which yields S.G. Iron. The slag produced can be utilized for the manufacture of tiles/cement

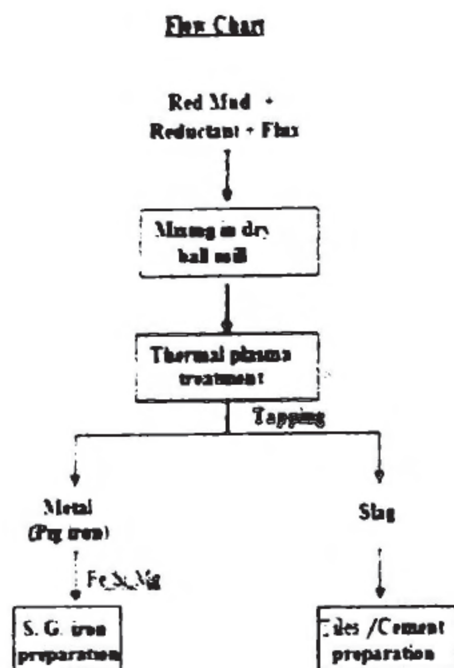


Fig.2 : Process Flow Diagram

Metallographic Studies of Red Mud, Pig Iron and Slag

(a) Red Mud:

The Red Mud sample was subjected to metallographic studies. The microstructure as well as the EDS analysis are shown in the Fig 3. EDS analysis data clearly indicate that the distribution of different elements in the Red Mud is not uniform. However many trace elements which remained undetected during bulk chemical analysis of red mud and slag were easily detected during EDS analysis. These data indicate the complex composition of Red Mud and consequently that of the smelter slag.

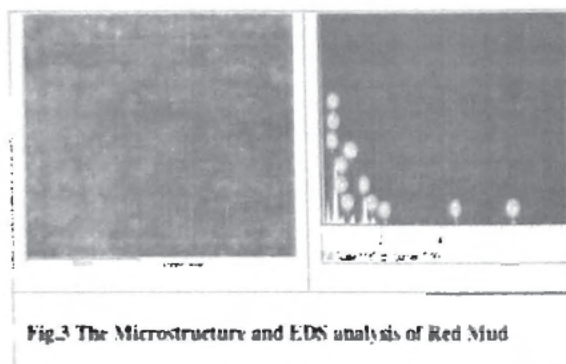


Fig.3 The Microstructure and EDS analysis of Red Mud

(b) Pig Iron

The Pig Iron produced by above method was subjected to metallographic studies. The microstructures of the sample were examined in a light microscope at various magnifications. Most of the samples developed a completely white or mottled structure

This is to be expected because Silicon was picked up by way of reduction of the silica in the red mud and the quartz added. However, the silicon in the metal was inadequate to cause graphitization. The secondary electron micrograph of a plasma smelted Pig Iron and EDS analysis are shown in Fig.4.

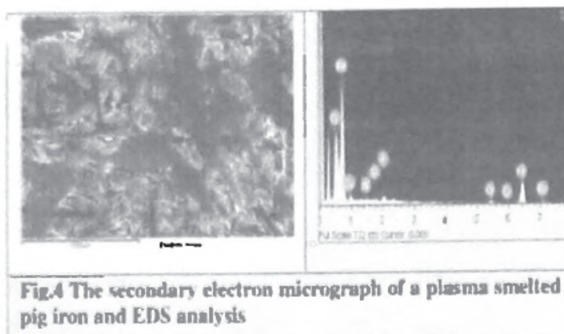


Fig.4 The secondary electron micrograph of a plasma smelted pig iron and EDS analysis

From this study it is observed that high concentration of Cr, Cu and P are found to be present in the particular spot analysed. The minor quantities of Cr_2O_3, P_2O_5 and CuO present in the Red Mud are completely reduced in the plasma smelter and are picked up in the Pig Iron.

It is interesting to note that Al has been picked up. Normally Al_2O_3 is so refractory that it is never reduced in the blast furnace or electric arc furnace. But the high temperature in the plasma reaction zone apparently favoured reduction of Al_2O_3 and pick up of Al in the metal, presumably as complex Fe-Al-carbide.

Titanium is also picked up most likely as a complex carbonitride, since the typical cuboidal precipitates of TiC could not be detected even after thorough scanning of the microstructure. Apart from reduction of iron oxide and silica, the reduction of other oxides also consumed the reductant. Naturally, such undesirable reduction reactions increased on prolonging the trial. Evidence of reduction of other oxides has been obtained through EDS analysis.

(c) Pig Iron Slag

The metallographic and EDS analysis of slag samples collected from the plasma reactor is shown in Fig.5.

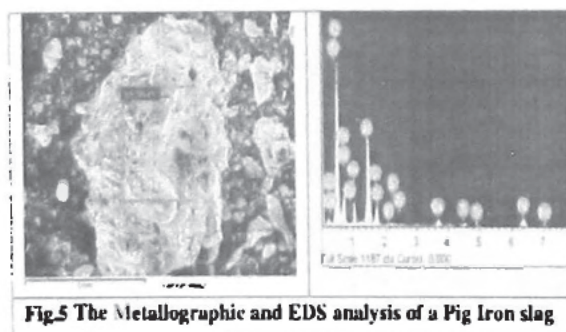


Fig.5 The Metallographic and EDS analysis of a Pig Iron slag

From this study it is observed that the Pig Iron slag is rich in Al_2O_3 along with SiO_2, MgO, FeO, CaO, TiO etc.

Conclusion

Thermal Plasma Technology offers a unique one step process for processing of Red Mud. Red Mud will be an important source of iron for the steel industry in future with appropriate technology. Present work takes a critical look into an innovative method for utilization of Red Mud-an industrial waste. The Thermal Plasma process has been developed for recovery of metal values from Red Mud as high value pig iron by optimizing process condition.

Optimised results shows that a basicity of 0.3 with a reduction time 25 minutes at plasma power 12.5 kW are optimized at which maximum recovery of pig iron to the extent of 70% can be achieved.

Acknowledgement

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Production of Pig Iron and Portland Slag Cement from Red Mud by Application of Novel Thermal Plasma Technique

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ABSTRACT

Red Mud of Indian origin contains around 50% plus of Fe_2O_3 depending on the source of bauxite and is considered as a hazardous waste for the Alumina Industry. For production of one tonne of Alumina employing the time tested Bayer's Process, around two tonnes of Red Mud is generated from three tonnes of Bauxite. No suitable avenues for bulk utilization of Red Mud have so far emerged.

In the present study, efforts have been made to produce pig iron from Red Mud containing major oxides viz. 37.52% Fe_2O_3, 20.48% Al_2O_3, 8.72%SiO_2 and 10.69% TiO_2 by employing state- of -the -art Thermal Plasma Technique. In the process, Red Mud in the powder form is charged into the Thermal Plasma Furnace at a temperature of 1600°C for a duration of 30 minutes. The pig iron thus produced, contains 93-95% Fe with recovery efficiency of 90% at optimized conditions. The residual slag produced in the process is utilised for manufacture of cement. The quality of cement so produced, matches well with the specification of standard Portland slag cement (PSC) presently in use in the constuction sectors. Thus the process can very well be considered as a zero waste process for production value added materials from Red Mud.

Key wards: Pig iron, Portland slag cement, Red Mud, Plasma Technique, Smelting reduction

1.0 INTRODUCTION

Red Mud, a by-product generated from the caustic leaching of bauxite to produce alumina in the Bayer Process, causes serious environmental problems and is considered as a hazardous industrial waste. During digestion of bauxite around two tons of Red Mud per one ton of alumina is produced. In India, various alumina producers viz. NALCO, BALCO, HINDALCO, INDAL, MALCO and VEDANT produce around 2 million tonne per annum of red mud which is stored by the companies in nearby ponds specifically made for the purpose which contains around 30-50 % iron. Utilization of Red Mud for production of cement, tiles, bricks and blocks etc has been tried by many researchers. However these efforts have resulted in partial utilization of Red Mud and the problem of bulk utilization of Red Mud still remains a challenge.

Thermal plasma is ecofriendly with very low effluent production which makes it increasingly attractive for various metallurgical applications. Generation of high density ionic charge helps in uniform heat transfer to the charged material at a faster rate, hence reaction time is very short. A clear slag-metal separation can be obtained in this process . Moreover, unlike blast furnaces, for plasma reactors, any specific shape or size of the feed is not required. Hence, fines can also be used as feed for the thermal plasma operations.

Since iron is a major constituent of Red Mud, it was thought prudent to utilise iron values in the form of pig iron from red mud utilizing the state-of-the-art of thermal plasma smelting technique. This novel process will help in production of pig iron which can be utilized for steel making. By employing this technology, techno-economic feasibility for bulk utilization of Red Mud can very well be established, thereby signifying the importance of production of wealth from waste materials.

1.1 Plasma smelting of red mud: Fundamental Principles

Plasma smelting of red mud was carried out in an extended arc plasma reactor using coke as a reductant. The Fe_2O_3 content in red mud is reduced to pig iron by carbon content of coke. The reduction of red mud with coke under thermal plasma may have the following chemical reactions.



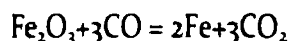
$$3\,Fe_2O_3 + CO = 2Fe_3O_4 + CO_2 \qquad (1)$$



$$Fe_3O_4 + CO = 3FeO + CO_2 \qquad (2)$$



$$FeO + CO = Fe + CO_2 \qquad (3)$$



$$Fe_2O_3 + 3CO = 2Fe + 3CO_2$$

The above referred chemical reactions can be extrapolated to the Boudward Reactions as followes:

Boudward Reaction

Carbon content in coke reacts with atmospheric O_2 to form.



$$C + O_2 = CO_2 \qquad (4)$$



$$CO_2 + C = 2CO \qquad (5)$$



$$2C + O_2 = 2CO - \Delta H \qquad (6)$$

CO is most stable at above 1000^{0}C. It is a good reducing agent and reduces Fe_2O_3 to Fe.

2.0 RAW MATERIALS

2.1 Red Mud:

Red mud of Indian origin was used for the present study. Its chemical composition is furnished in Table 1.

Table 1: Chemical characteristics of red mud:-

Al_2O_3,%	SiO_2,%	Fe_2O_3,%	Fe(T),%	CaO,%	TiO_2,%	P_2O_5,%	V_2O_5,%	Na_2O,%	LOI,%
20.48	8.72	37.52	26.32	3.86	10.69	0.339	0.325	4.65	11.98

2.2 Coke:

The chemical composition of coke used for the study is furnished in Table 2.

Table-2 Chemical composition of coke

Volatile (%)	Fixed Carbon (%)	Ash content (%)
4.6	86.74	12.02

2.3 Lime Stone

The lime stone used as a flux in the present studies has the following chemical composition as furnished in Table 3.

Table3: Chemical composition of lime stone

CaO (%)	MgO (%)	SiO_2 (%)
42.45	2.38	13.42

3.0 EXPERIMENTAL

Smelting studies were carried out in a 35 kW dc extended transferred arc plasma reactor. The reactor is basically a pot type reactor with zircon coated graphite crucible as the furnace hearth, which is thermally insulated by bubble alumina. Graphite electrodes are arranged in a vertical configuration. The bottom electrode (anode) is kept stationary and top one (cathode) with an axial hole for passing the plasma forming Argon gas is actuated by rack and pinion mechanism for arc stabilization. The hearth is provided with a graphite spout to tap both metal and slag. A schematic diagram of the reactor is given in Fig 1. Flow of argon gas was regulated at 1.0 liters/minute throughout the period of experiment. An average arc voltage of 50 V and 250

amperes current were maintained during the experiment. Temperature observed in the plasma reactor was 1400-1600°C.

Dry red mud along with coke and lime stone was charged to the reactor. The amount of reductant was kept at 20% , the basicity was varied from 0.25 to 0.5 and the reduction time was varied from 25 to 35 minutes.The plasma power input was maintained at 15 kW through out the study. It is observed from the experimental data, the maximum iron recovery obtained is 68% from 1kg scale of dry red mud with the following condition- reductant: 20%, basicity: 0.25, smelting time:30min, and Plasma Power input :15kW.

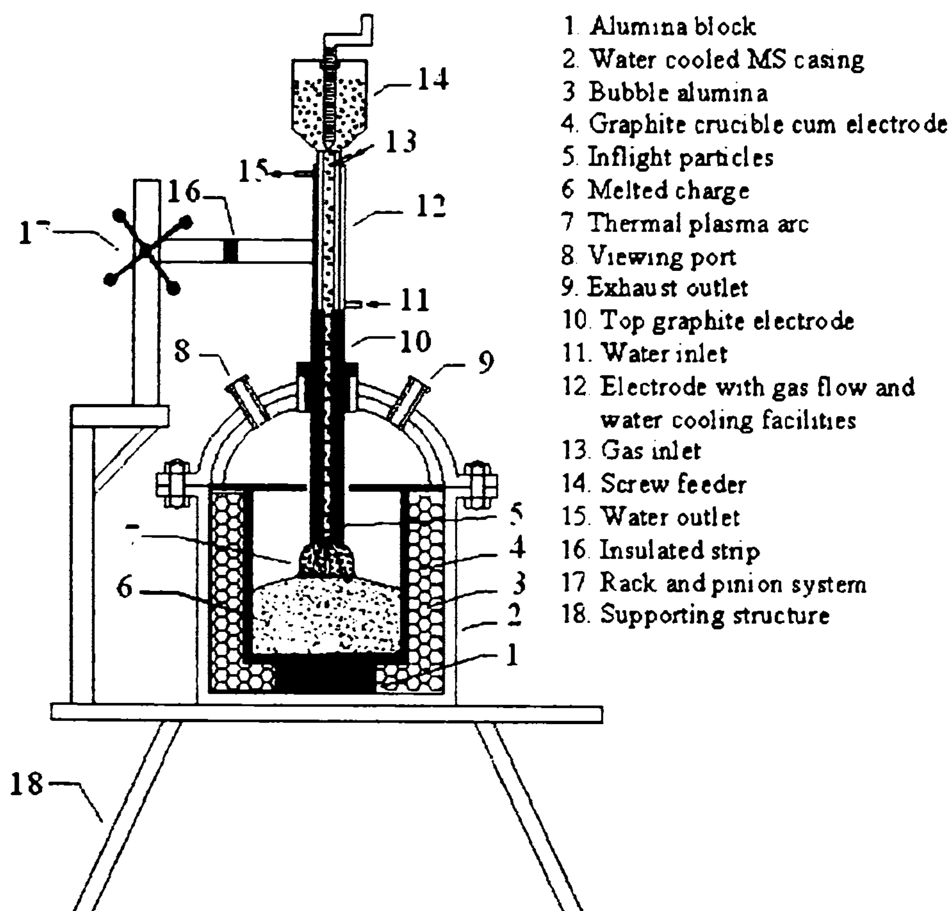


Fig. 1 : Schematic diagram of extended arc thermal plasma reactor.

3.1 Experimental Procedure

Initially red mud, coke and dolomite / limestone/ flourspar (flux) powder of required composition were thoroughly mixed and charged inside the graphite crucible. Argon gas was used as

plasmagen gas and was passed through the top electrode at a rate of one litre per minute. The arc was struck and the current of 250 amperes was maintained with an arc voltage of about 60 volts. The plasma arc was continued for 20 to 30 minutes to complete the chemical reaction. The temperature of the molten bath was measured by using Minolta optical pyrometer. At the end of the smelting, the tap hole was opened and the molten pig iron and slag were allowed to cast graphite mould. The flow chart of the process is furnished in Fig.2.

FLOW CHART

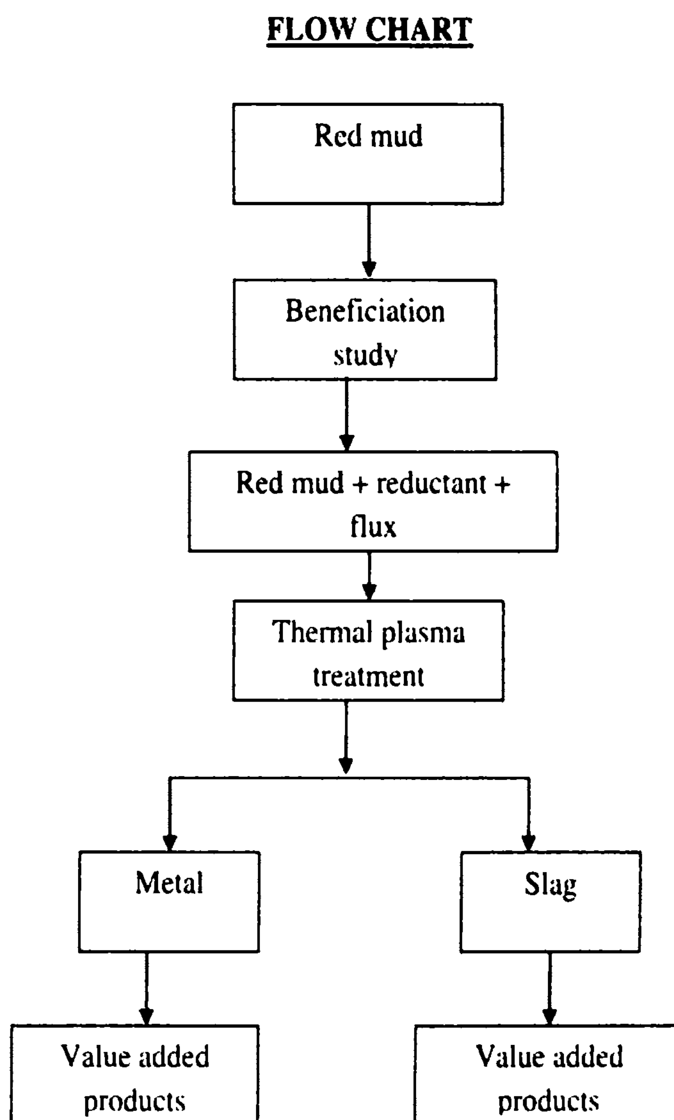


Fig.2: Flow chart of the process know- how

4.0 RESULTS AND DISCUSSIONS

The red mud along with graphite and flux (Limestone/ flourspar) were smelted in 35KW extended arc plasma reactor. The main aim and objectives of the work was to find out higher recovery of iron. To achieve this, the process parameters like basicity and reduction time were studied

4.1 Effect of basicity on the recovery of pig iron:

Basicty plays an important role in the production of Pig Iron from Red Mud. The basicity ranging from 0.25 to 0.50 has been studied. It is observed that the maximum recovery of 68% was achieved with the basicity of 0.35. With further increase of the basicity, the metal recovery decreases (Table-4). This may be due to the fact that presence of alumina makes the slag more viscous.

Table 4: The effect of basicity on the metal recovery at reductant - 20% & time - 30 min

Exp.No.	Basicity	Metal Wt (gm)	Slag Wt (gm)	% of Metal recovered	E.C of Metal Kwhr/kg
1	0.25	156	495	60	40.06
2	0.35	178	550	68	35.11
3	0.50	128	642	49	45.29

4.2 Effect of amount of reductant on metal recovery at basicity 0.25 and time 30min.

The effect of reductant on the recovery of Pig Iron was studied in the range of 10 to 30% of the charge mix, keeping basicity at 0.25 and time 30 min. In this case coke is acting as the reductant. The results are shown in Table-5. From the results obtained, it is observed that the recovery of metal is increasing with increasing the amount of reductant from 10 to 20% and thereafter, a decrease in trend is observed. The reasons are not clear and needs further in-depth investigation.

Table 5 : Effect of reductant: Basicity -0.25, time - 30 min.,

Exp. No.	Reductant %	Metal Wt. (gm)	Slag wt.(gm)	% of Metal	E.C of metal Kwhr/kg
1	10	85	568	31	73.53
2	15	162	420	60	38.58
4	20	178	452	68	35.11
5	25	149	508	55	41.95
6	30	25	530	9.0	250.00

4.2.1 Effect of amount of reductant on metal recovery at basicity 0.35 and time 30min.

The effect of reductant on the recovery of Pig Iron was also studied in the range of 12 to 20% of the charge mix, keeping basicity at 0.35 and time 30 min. In this case coke is also acting as the reductant. The results are shown in Table-6. From the results obtained, it is observed that the recovery of metal is increasing with increasing the amount of reductant from 12 to 20%.

Table 6 : Effect of Reductant: basicity -0.35 & time constant -30 min

Exp.No.	Reductant (%)	Metal Wt (gm)	Slag Wt (gm)	Metal Recovered (%)	E.C of Metal Kwhr/kg
4	12	160	525	61	39.06
5	15	105	665	64	49.60
6	20	178	550	68	35.11

4.3 Effect of reduction time on metal recovery

The recovery of Pig Iron production depends on the reduction time. The time range from 25 to 35 minutes have been studied. The results are shown in the Table-7. It is observed that there is increase in the recovery of Pig Iron up to 30 min and thereafter it decreases. This may be due to evaporation of metal values during prolonged smelting operation period. This may be due to the reverse reaction of iron to form complex failite slag. Further investigation in this line is being carried out.

Table 7: Effect of time at basicity - 0.35 & reductant constant - 20%

Exp.No.	Time (min)	Metal Wt (gm)	Slag Wt (gm)	Metal Recovered (%)	E.C of Metal Kwhr/kg
7	25	63	566	24	82.67
8	30	178	550	68	35.11
9	35	147	502	56	49.60

4.4 Mineralogical Characterisation: XRD analysis of Metal and Slag

The XRD pattern of metal is shown in Fig 3. It mainly contained metallic Fe. The chemical analysis showed that it contained 96% Fe. The impurities present were C, Si, O, and P. Carbon peaks may be due to the unreacted coke. The XRD pattern of the slag was shown in Fig 4. It showed the peaks of Na_2O, Fe, FeO, Al_2O_3, SiO_2, CaO, MgO and TiO_2. The peaks of the TiO_2 exclusively in the slag phase indicated its refractoriness towards reduction by Carbon.

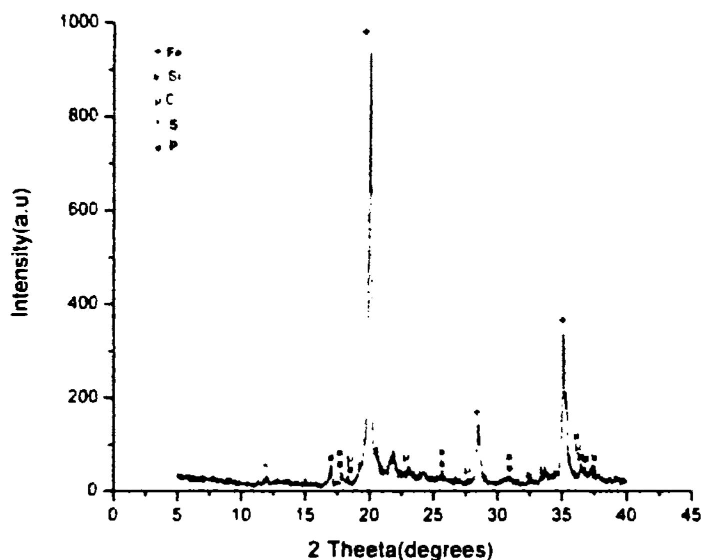


Fig : 3 XRD analysis of metal (pig iron)

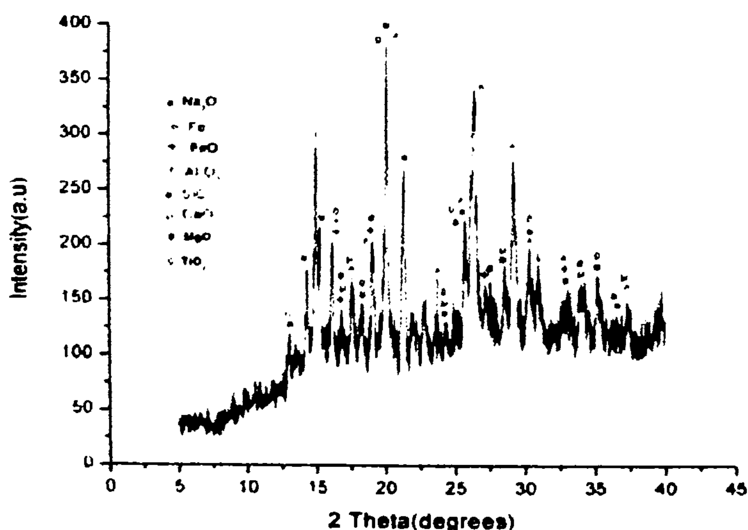


Fig : 4 XRD analysis of slag

4.5 Establishing Feasibility for utilisation of slag in cement making

The slag sample obtained after iron recovery has been used as a blending material with OPC Cement to evaluate its cementation behaviour.

The iron extracted red mud slag is used at 30% with 67% OPC-53 Grade cement and 3% Gypsum by weight in 3kg scale for preparation of blended cement by grinding in ball mill for evaluation of hydration behaviour and development of crushing strength (Table-8).

The strength of the red mud-slag blended cement has been determined in 1:3 cement: sand ratio by making (76x76x76) mm size cubes (as per BIS specifications). The cubes are water cured and strength has been determined at an interval of 1,3,7,14,21, 28 days of water curing. The strength of the iron extracted red mud slag cement cube has been compared with the cubes made using Portland Slag Cement (PSC) as shown in Table 9.

Table 8: Cement Preparation (3kg scale):

Mix composition	Wt%	Wt(kg)
OPC (53 Grade)	67	2.01
Redmud slag	30	0.90
Gypsum	3	0.09

The cubes (76x76x76) mm has been prepared at water-cement ratio of 0.4 using cube vibrator by maintaining 2 minutes of vibration time. The cubes after 24 hrs of casting are de-moulded and immersed in water for curing. The compressive strength after 24 hrs of casting and after water curing of 3, 7, 14, 21, 28 days has been examined. Similarly, the controlled cement (PSC) has been used to prepare cubes in similar manner for comparison of comprehensive strength.

Table 9: Comparision of properties of Portland Slag Cement (PSC) with the cement blended with 30% Red mud slag

No of days	Compressive strength of MPA	
	Cement blended with 30% Red mud slag	Portland Slag Cement
1	13	13
3	17	22
7	22	28
14	26	34
21	26	38
28	22	48

From the above experimental results it is observed that the red mud slag has come binding property which shows early strength comparable with PSC, but in later days i.e. after 21 days the hydration strength decreases and do not conform to the requirement of standard cement. This shows that there is a need of improvement in slag chemistry to improve the better hydration behaviour in cement making.

5. CONCLUSIONS

The following conclusions can be drawn based on the above research findings:

- Production of pig iron from red mud is possible by application of thermal plasma technique in laboratory scale. However its techno-economy feasibility needs further scale up of operations.
- It is also possible to produce portland slag cement (PLC) from the slag generated in the process during the convertion of red mud by applicaion of such novel thermal plasma technique too, thereby making it a zero waste process.

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Processing of red mud by low temperature microwave hydrogen plasma for production of iron: An eco-friendly technology

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Abstract

Red mud is produced in huge quantities during the processing of bauxite for the production of alumina. So far, few economically attractive processes have been developed for bulk utilization of red mud. Researchers are trying to develop interesting processes and products from this waste material; success achieved so far is restricted to laboratory, pilot scale, isolated or minor volume utilization applications and processes. Red mud of Indian origin contains around 45 – 55 % Fe_2O_3, 11 % TiO_2, 20 % Al_2O_3, 9 % SiO_2 and other associated oxides in minor quantities. Iron being the major component, bulk utilization of red mud will be difficult without an economically and technically viable process being developed for the production of iron from red mud. Indian iron ore containing 45 % Fe_2O_3 is considered as the cut-off grade for the economic production of iron. Accordingly, red mud of Indian origin can be considered as a low grade iron ore. The present study examines the processing of Indian red mud by Low Temperature Hydrogen Plasma for the production of iron in eco-friendly manner at laboratory scale. The iron produced contains 95 % Fe with low carbon and sulphur. Water, which can be recycled, is produced as a by-product of the process.

Key words: Red mud; hydrogen reduction; microwave hydrogen plasma reactor; iron from red mud.

1 Introduction

Red mud is a byproduct generated during the processing of bauxite with caustic soda utilizing the Bayer process. It is considered as a hazardous material and till today few economically interesting applications or processes have been developed for its bulk utilization. Researchers have tried to produce pig iron from red mud by the application of plasma smelting technology [1], production of pig iron and portland slag cement from red mud by application of novel thermal plasma technique [2], production of ordinary Portland cement (OPC) from red mud [3], and processing of red mud for the production of wood substitute materials [4]. All efforts in this direction have so far been restricted either to laboratory or pilot scale processes. Iron oxide is a major constituent of red mud and for this reason it can very well be considered as a low grade iron ore. Red mud of Indian origin contains around 45 – 55 % Fe_2O_3, 11 % TiO_2, 20 % Al_2O_3, 9 % SiO_2 and other associated oxides in minor quantities. The quantum of generation of red mud by the alumina industries all over the globe warrants its gainful utilization in bulk quantities. An important option available presenting to researchers is extraction of iron from red mud in a most eco-friendly manner.

The reduction of Fe_2O_3 present in red mud to metallic iron can be achieved either by carbothermic or hydrogen reduction processes. The carbothermic reduction process involves a blast furnace route

for production. However, this process is not free from pollution and emits large quantities of carbonaceous gases which add to global warming. It has been estimated that for production of one tone of iron, around three tones of green house gases are generated. Under the circumstances, industry have few other alternatives but to follow an eco-friendly (and lower energy cost) path way for production of iron through a hydrogen reduction process. Researchers elsewhere have tried to produce metallic iron from iron ore employing the hydrogen reduction process by using hydrogen gas as reductant in a high temperature furnace [5]. This process has limitations, such as it being a time consuming process associated with low yield and moreover, consumption of hydrogen gas was also increased.

The answer to this challenge lies with the state-of-the-art technology for production of metallic iron from iron ores by application of the low temperature Microwave Hydrogen Plasma Reduction route. Through this route, iron was extracted successfully from iron ores as Direct Reduced Iron [6].

Once researchers successfully accomplished such an eco-friendly reduction process, the process know- how was then suitably replicated for production of iron from red mud through application of a Low Temperature Microwave Hydrogen Plasma Reduction Process using hydrogen gas as a reductant. The product so obtained contains 95% Fe with low carbon and sulphur. The process is eco-friendly and free from carbon. Moreover, 'water' is generated in the process as a by-product which can be recycled when commercially used.

2 Raw Materials

The red mud of Indian origin was used as principal raw material for the study. The mineralogical composition and chemical analysis of red mud are furnished in Figure 1 and Table 1 respectively. The other raw materials used for the study were hydrogen gas of 99.9% purity and argon gas.

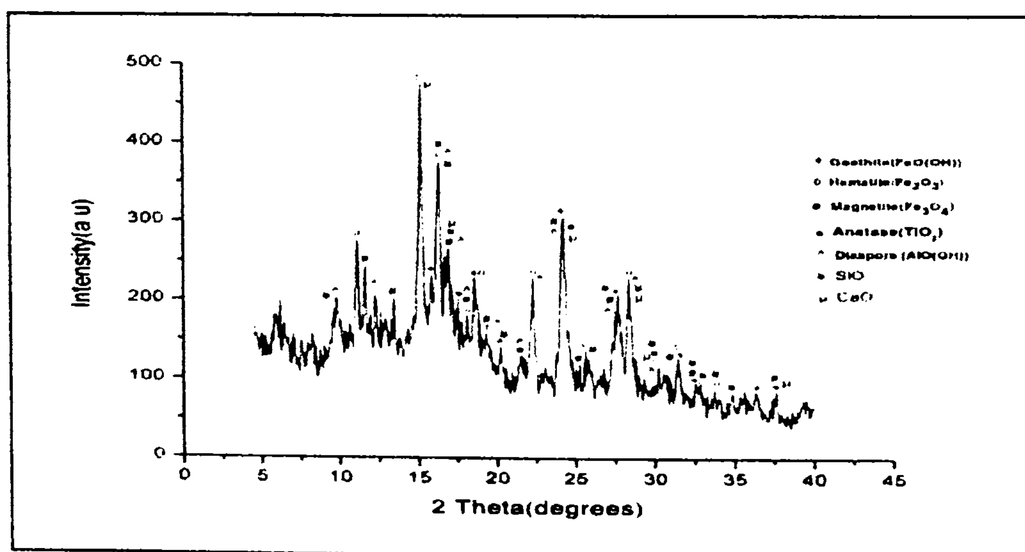


Figure1. Mineralogical composition of red mud of Indian origin.

Table 1. Typical chemical analysis of Indian red mud.

Input material	Fe_2O_3	SiO_2	TiO_2	Al_2O_3	Na_2O	MgO	CaO	LOI
Indian red mud	53.6	18.9	2.20	4.88	8.29	0.21	0.54	9.30

3 Experimental

A red mud sample was subjected to crushing and grinding to bring the size to -100 mesh which was then pelletized to 40 mm diameter and 3 mm height using an electrically operated automatic briquetting press by addition of 1 – 2 % of water with respect to the amount of sample taken for the study. This was then dried in the oven at 100 °C for 2 hours. The dried pellet was then subjected to Hydrogen Plasma Reduction in Microwave Hydrogen Plasma Reactor. The experimental parameters like flow of hydrogen, reduction temperature, reduction time, pressure, and the power input were studied for the reduction of the iron content in red mud to produce direct reduced iron (DRI). The raw materials and the products were analyzed for their chemical compositions and mineralogical characters. The reduction studies were carried out as per the process flow sheet given in Figure 2.

3.1 Microwave Hydrogen Plasma Reduction Process

The reduction of the raw red mud pellet to produce DRI was carried out in a specially built Microwave Hydrogen Plasma Reactor of 6 kW power. The plasma is generated by microwave assisted thermal plasma process. The schematic diagram of Microwave Hydrogen Plasma Reactor with in-situ photograph of the reactor chamber is shown in Figure 3. The system has provision to inject hydrogen gas from the top into the chamber through a safety valve and the flow of the gas can be controlled by a mass flow controller.

The temperature of the molybdenum sample holder is measured by means of an infrared (IR) pyrometer. The microwave power can be varied to generate the plasma over a range of temperatures. The high frequency waves interact with the hydrogen gas to produce the hydrogen plasma. The plasma produced in this manner covers a region up to about 6 to 8 cm above the sample. The hydrogen molecules enter the plasma zone and become part of it. The hydrogen molecules under the influence of plasma dissociate in to atomic and ionic forms which reduces the iron oxide present on the surface of red mud pellet into metallic iron. These ionic charged particles of hydrogen return immediately to hydrogen molecules when they exit from the plasma zone.

In all the experiments, samples were kept on a molybdenum sample holder, and the sample holder was in turn placed at the centre of the reactor chamber. Since the rector chamber is water cooled, the outer surface of the chamber remains at room temperature during the experiments. The extent of reduction with the variation in process parameters, such as microwave power, hydrogen flow rate, pressure, temperature and time, was recorded by noting the loss in weight of the pellet. After each experiment, the reduced red mud pellet sample was ground and mixed well, and then a representative sample was taken for analysis. An X'Pert PRO-PAN analytical model No. 3040160 was used for X-Ray Diffraction (XRD) studies of the phases in the reduced red mud pellet. The quantitative estimation of the phases was done by using the wet chemical analysis procedure for the total iron, metallic iron, ferrous iron, silica and alumina. Table 2 describes the chemical analysis of the reduced red mud pellet. The schematic diagram of the process know how employed is given in Figure 2.

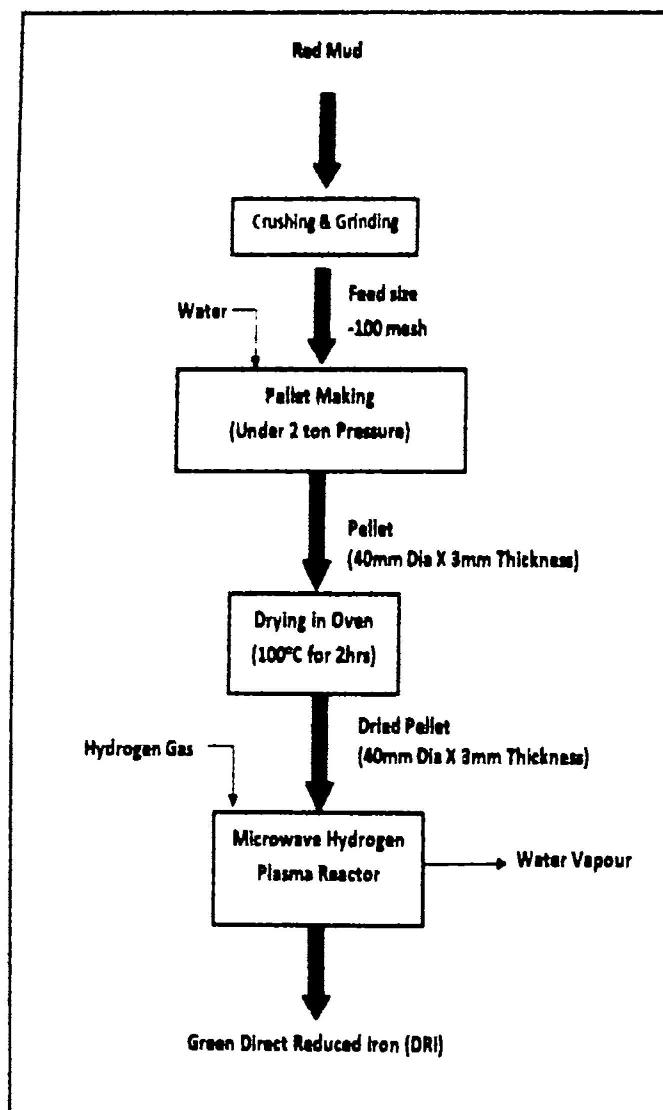


Figure 2. Process flow sheet for the production of green direct reduced iron (DRI) from red mud.

Table 2. Chemical analysis of reduced red mud pellet.

Input material	Fe(T) (%)	Fe(M) (%)	FeO (%)	SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)
Reduced red mud pellet	87.89	77.95	12.00	7.89	2.44	1.78

Schematic: Microwave Hydrogen Plasma Reactor

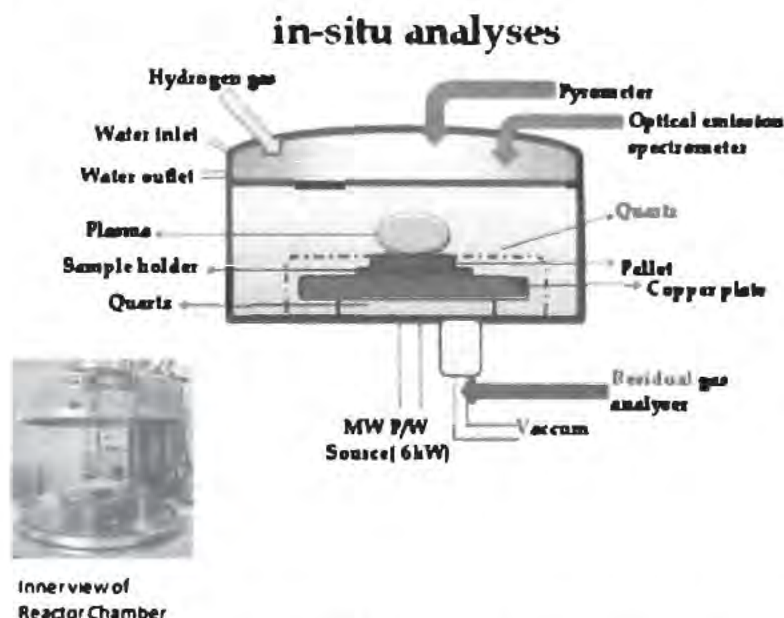
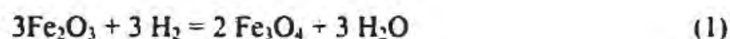


Figure 3. Schematic diagram of microwave hydrogen plasma reactor

4 Results and discussions

There is no doubt that hydrogen can be used as a reducing gas in direct reduction processes. A careful analysis of the literature shows that iron oxides can be reduced by hydrogen gas and in this contest, a series of relevant reactions are as follows:



$$3Fe_2O_3 + 3\ H_2 = 2\ Fe_3O_4 + 3\ H_2O \qquad (1)$$



$$w/(4w-3)Fe_3O_4 + H_2 = 3/(4w-3)Fe_wO + H_2O \qquad (2)$$



$$Fe_wO + H_2 = w\ Fe + H_2O \qquad (3)$$



$$Fe_3O_4 + 4\ H_2 = 3Fe + 4\ H_2O \qquad (4)$$



$$2H_2 + O_2 = 2H_2O \qquad (5)$$



$$2Fe + O_2 = 2FeO \qquad (6)$$



$$4H + O_2 = 2H_2O \qquad (7)$$



$$4H^+ + 2O^{2-} = 2H_2O \qquad (8)$$

It has been shown that molecular hydrogen is a good reductant for iron oxides, which follows the reactions (1) - (3). In these reactions, w is the atomic ratio of iron to oxygen in wüstite and is

known to vary from 0.95 along the wüstite-iron boundary to 0.85 along the wüstite-magnetite boundary. Below 833 K wüstite is unstable and hence magnetite is reduced directly to metallic iron as per reaction (4). It is also known that reactions (2) and (3) are endothermic at any temperature, where as reaction (1) is weakly endothermic in the temperature range 827- 913 K and exothermic at other temperatures.

Figure 4 presents the Ellingham-Richardson Diagram showing the reducing potential of hydrogen (5) in comparison to other reactions, its transformation of FeO to Fe as shown in reaction (6). As seen from Figure 4, molecular hydrogen reduces Fe_2O_3 and Fe_3O_4 quite easily, though ΔG^0 values for reactions (5) & (6) are much closer. However, it is also seen from the Figure 3 that ΔG^0 values for reactions (7) & (8), involving atomic and ionic hydrogen species respectively, are very high and negative in comparison to reaction (5), which involves molecular hydrogen. The two species H and H^- are provided by the plasma. In other words, in the plasma state, both H and H^+ can coexist. In the hydrogen plasma smelting reduction process, these hydrogen plasma states do also exist for production of iron [7 - 9]. Keeping these in view, efforts were directed at the production of iron from the red mud of Indian origin using the Microwave Hydrogen Plasma Reactor, using various experimental parameters. The results were shown in Table 2.

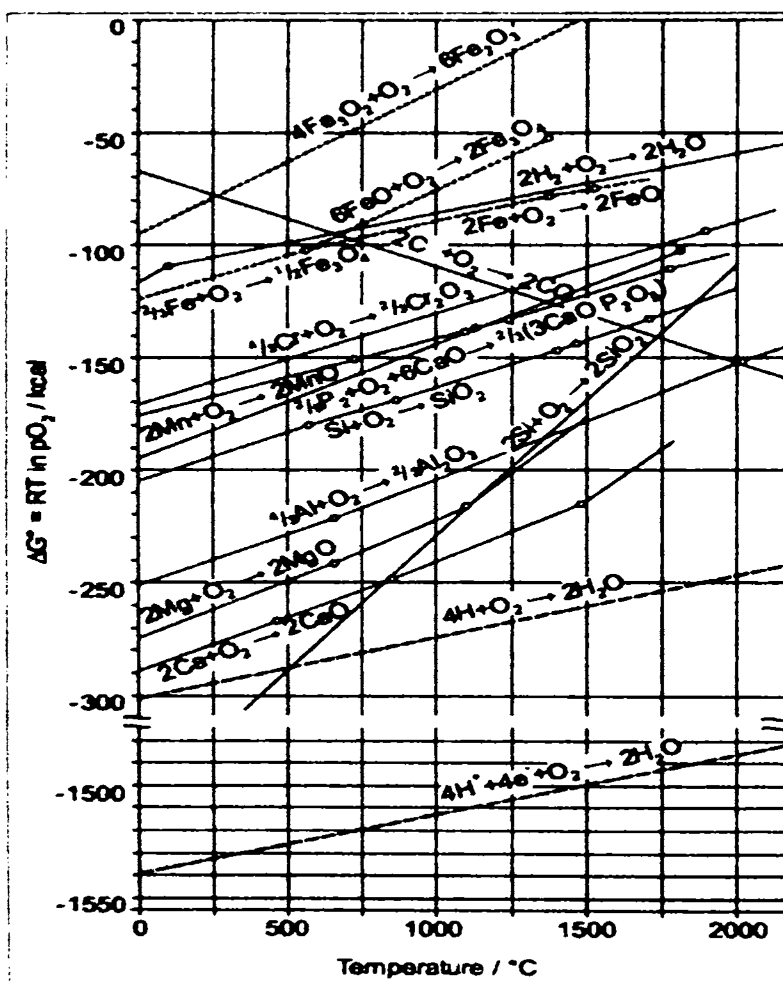


Figure 4. Ellingham-Richardson- Diagram.

4.1 Effect of time

The hydrogen gas starts reacting with the iron oxide present in the red mud pellet from the surface and gradually penetrates the body of the pellet for which reduction time plays an important role. The experiments were carried out at various reduction time intervals keeping other parameters constant as shown in Table 3. From this table, it is observed that the percentage reduction of iron oxide to iron present in red mud pellet increases with increasing time. At 120 minutes, reduction is 98.23 %, and that at a low temperature of 300 °C. The XRD results in Figure 5 indicate that over time, the iron peaks become prominent, and its presence is established.

Table 3. Reduction of compacted red mud pellet by Microwave Hydrogen Plasma at various time intervals (temperature: 300 °C, microwave power: 750 W, pressure: 5.33 kPa, hydrogen flow rate: 3.33 mL/s).

Sl.No	Time (min)	Initial weight (g)	Final weight (g)	Reduction (%)
1	15	15.023	14.170	20.18
2	30	15.015	13.150	45.69
3	45	14.910	12.460	64.30
4	60	14.910	12.210	70.56
5	120	14.920	11.210	98.23

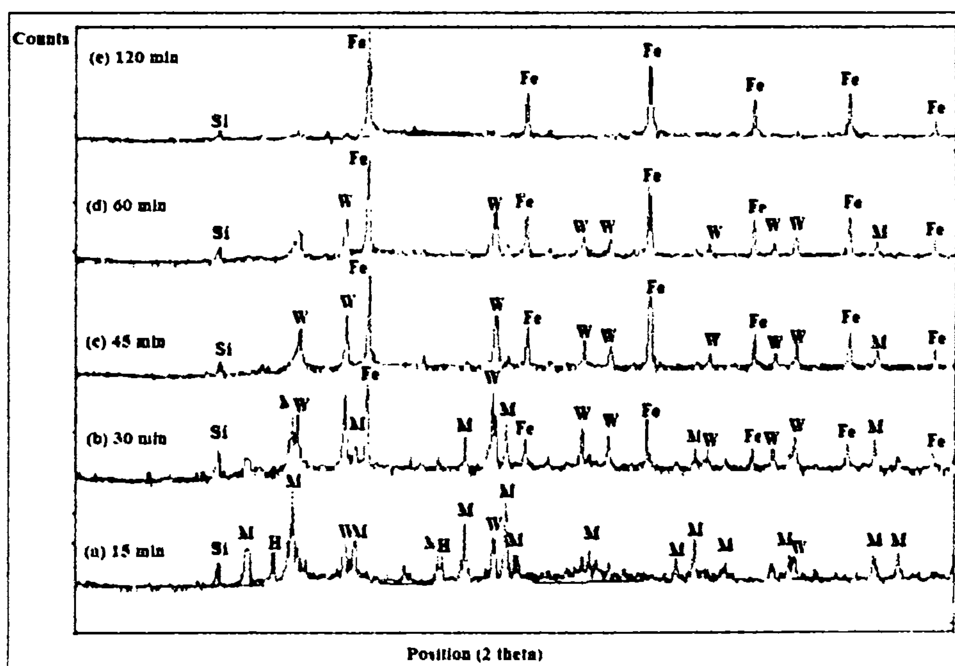


Figure 5. XRD Diffraction plots for red mud pellet reduced by Microwave Hydrogen Plasma at various time intervals.

4.2 Effect of temperature

As seen in Table 3, even at a low Temperature of 300 °C, a percentage reduction of 98.23 was achieved at a time interval of two hours duration. Accordingly, further experiments were carried out to see both the effect of temperature and time on percentage reduction of iron oxide present in the red mud pellet. The results obtained from these studies are shown in Table 4 , which indicates that the percentage reduction in the pellet increases from 70.56 to 99.3 with increase in temperature from 300 to 800 °C, keeping reduction time a constant 60 minutes. From the results of Tables 3 and 4, it can be concluded that the percentage reduction of iron oxide is faster at a higher temperature (800 °C) than at 300 °C. It may be because of the fact that more and more of excited hydrogen species are taking part in the reduction process as temperature gradually increases. The XRD results indicate the prominence of iron peaks with variation in temperature (Figure 6).

Table 4. Reduction of compacted red mud pellet by microwave hydrogen plasma at various temperatures (time: 60 min, microwave power: 750 W, pressure: 6.66 kPa, hydrogen flow rate: 3.33 mL/s).

Sl.No	Temperature (°C)	Initial weight (g)	Final weight (g)	Reduction (%)
1	300	15.023	14.170	70.56
2	450	15.015	13.150	89.7
3	600	14.910	12.460	91.6
4	800	14.910	12.210	99.3

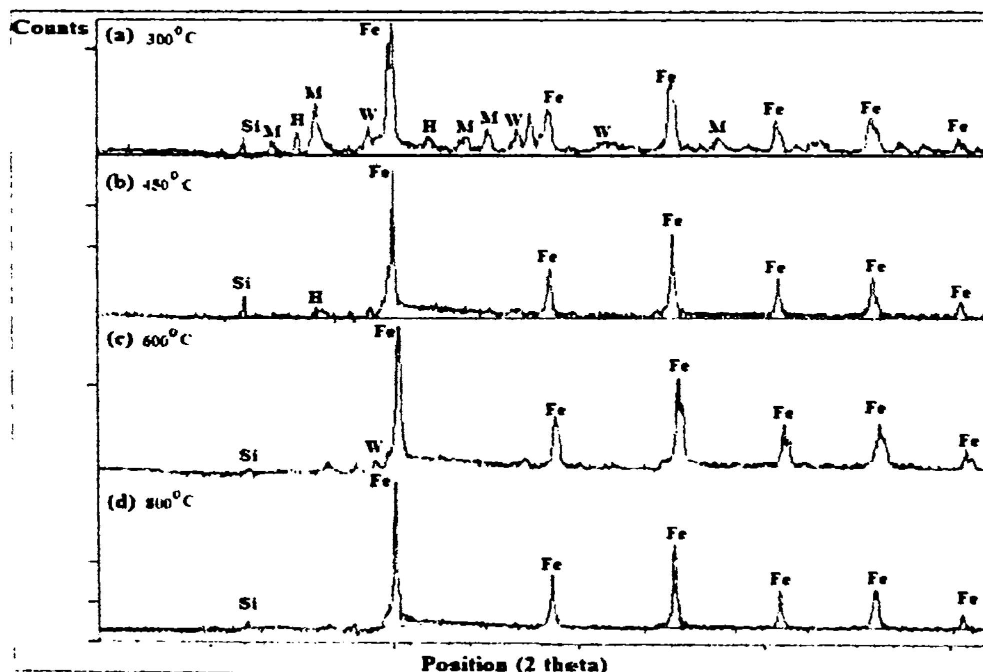


Figure 6. XRD Diffraction plots for red mud pellet reduced by Microwave Hydrogen Plasma at various temperatures.

4.3 Reaction mechanism at the surface of the red mud pellet

In the Microwave Hydrogen Plasma Reactor, the hydrogen gas passes from the top of the reactor through the plasma zone and comes in contact with the surface of the red mud pellet. At the surface of the pellet, the gas-solid reaction takes place. Figure 7 indicates the path way of the reaction mechanism from raw red mud pellet to iron. In the context of gas-solid reaction, in addition to ionic and atomic species of hydrogen, the role of vibrationally excited hydrogen molecules has also been emphasized in the literature [2]. It has been reported that vibrationally excited hydrogen molecules stimulate the chemical process through their surface dissociation and diffusion of hydrogen atoms into the crystal structure of iron oxide present in red mud pellet. The experimental data of P. Rajput et al [2] provide evidence to the presence of vibrationally excited hydrogen molecules. Therefore, similar reaction mechanism may also be happening at the surface of the red mud pellet for the production of iron. Accordingly, it can be concluded that vibrationally excited hydrogen molecules are probably the species responsible for reduction of iron oxide present. Another alternate possibility may be the contribution of the atomic and ionic species of hydrogen plasma as a catalyst to drive reduction of iron oxide in the pellet. However, more studies are required to obtain further insight with respect to reaction mechanism at low temperature.

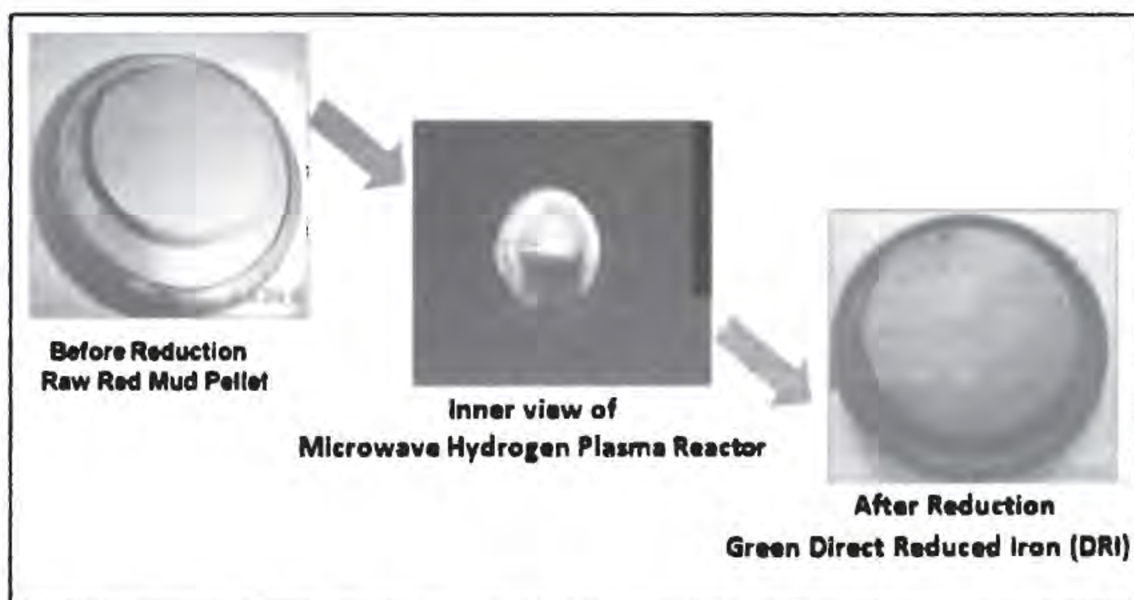


Figure 7. Microwave Hydrogen Plasma reduction of raw red mud pellet for production of Green Direct Reduced Iron (DRI).

5 Eco-friendly process

The conventional process of iron making through DRI route has limitations. It requires a high temperature of around 1200 °C to convert iron oxide in to metallic iron. The process presented here on the other hand, needs only a temperature of around 300 °C to carry out the reduction and is more energy and cost effective. The process is green in character as the central process is carbon free and environmental friendly, and generates 'water' in the process as a by-product which can be recycled when used in the commercial process.

6. Conclusions

From the above experimental evidences and observations, it can be concluded that red mud containing around 53.6 % Fe_2O_3 and some appreciable quantities of Al_2O_3 and other associated metal oxides in minor quantities, can very well be reduced to iron by the application of Microwave Hydrogen Plasma technology.

The process has been successfully demonstrated at laboratory scale, but needs to be demonstrated at pilot scale before its commercial feasibility is established. CSIR-IMMT, Bhubaneswar, Odisha, India is in possession of laboratory scale technology for production of iron from red mud of Indian origin and the know-how is readily available for commercial exploitation.

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CHAPATER 5

Development of Bauxite, Alumina, Aluminium Based Industries & Allied Sectors

STUDIES ON METAL FLOW FROM KHONDALITE TO BAUXITE TO ALUMINA AND REJECTS FROM AN ALUMINA REFINERY, INDIA

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Keywords: Khondalite, Bauxite, Alumina, Undigested Sand, Red Mud, Metal distribution

Abstract

Alumina is produced from khondalite hosted bauxite of Indian origin in the Alumina refinery employing the time tested Bayer's Process. In the process, about 40% of unwanted elements are rejected as undigested sand and red mud. During the whole cycle; major, minor, trace and RE elements in these litho-units get redistributed, either depleted or enriched. Khondalite, the source rock of bauxite, is rich in silica, moderate in alumina and iron with minor titanium. Bauxite becomes rich in alumina and iron with subordinate titanium and negligible silica. After alumina recovery from bauxite, most of the valuable metals including REE get accumulated in the refinery rejects. The studies, while establishing the extent of various metals dispersed in khondalite, bauxite, undigested sand, red mud and alumina also reveals the state of enrichment of valuable metals in undigested sand and suggests possible means to recover some of them.

Introduction

Alumina is produced from khondalite hosted bauxite of Indian origin in the Alumina refinery employing the time tested Bayer's Process. When 2.4 MT of bauxite per annum is processed in a refinery it produces approximately 0.8 MT of alumina. During the process of alumina production, about 60% of unwanted gangue is rejected as 'undigested sand' and 'Red Mud'. Out of total quantity of 70 Million tonne per year (Mtpy) of red mud in the world, India accounts for about 2Mtpy. This industrial waste material poses tremendous environmental and disposal problems. With the anticipated expansion of alumina Industry in the country, Indian alumina plants have to dispose off over 5Mt of this red mud every year.

Aluminium oxide, from which aluminium metal is extracted, constitutes only 38 to 60% of bauxite ore. The rest is made up of Fe_2O_3, SiO_2, TiO_2 and scores of other metallic oxides. After dissolution of alumina in caustic soda, these impurities remain in suspended form which is separated out after being washed and then pumped as slurry to the nearby pond. During Bayer's process, all alumina content from the bauxite is not recovered and appreciable volume goes into red mud along with other valuable metals. Though some studies have been undertaken to recover metal values from red mud, they are not considered economically viable. Moreover, availability of high-grade ores of hematite, ilmenite, rutile, bauxite, monazite, vanadiferrous iron ore etc. in India, restricts attempts to recover any metal value from the red mud. Nevertheless, some metal values may be recovered in view of their scarcity and significance.

This paper while enlisting the extent of various metal values dispersed in khondalite (host rock of bauxite), bauxite (the feed to the alumina refinery), undigested sand and red mud (the rejects) and aluminium oxide (the product) discusses the dispersion pattern of metal values in all these litho-units, enrichment of valuable metals in undigested sand and suggests possible means to recover some of them.

Materials and Methods

The host khondalite, the feed bauxite, the rejects and the product samples were collected from one of the typical refineries of India. The recovery of aluminium oxide from bauxite through "Bayer's process" involves different stages. The main stages of Bayer's process are digestion of crushed bauxite → de-sanding → de-silication → settling → filtration → washing → pumping to red mud pond. The red mud samples from different stages were also collected for the study. The five samples collected are from Digested Mud (DM), De-silicated Mud (DSM), Settler Mud (SM), Washer Mud (WM) and Mud to Pond (MTP). In order to characterize and establish the mineralogical variation from bulk feed to mud to pond sequentially, each sample was studied by means of XRD (Philips) and SEM (Jeol). To ascertain the metal concentration (major and minor) from host rock to feed bauxite and the product to rejects, the samples were analyzed by XRF (Philips), and ICP-MS techniques (trace and REE).

The trace and rare earth elements (REE) were analysed at NGRI, Hyderabad, India using Inductively Coupled Plasma-Mass Spectrometer (ICP-MS). The ICP-MS used was a plasma quad PQ-1 (Fisons Instruments, U.K) controlled by an IBM PC-XT microcomputer and associated software. The ion-detection system and the data acquisition system consists of a Channeltron Electron Multiplier (CEM) and a multi channel analiser (Tracor Northern). To analyse the trace and REE the standard acid dissolution procedure was adopted for sample preparation as prescribed by Balaram et al.[1]. The sample solutions were prepared by HF-HNO3 acid digestion with Indium (100mg/ml) as internal standard. To ensure precision of the data a set of international ore standards of different chemical compositions were analysed along with the sample

Results and Discussion

Mineral distribution in host rock, feed, rejects and products

Broad Litho type	Nature of Sample	Major Phase	Minor Phase
Bauxite	Pink	Gibbsite	Kaolinite Muscovite
	Yellow	Gibbsite, Goethite	Muscovite
	Brown	Gibbsite, Goethite	Hematite, Sillimanite
	Black	Hematite Gibbsite	
	Red	Goethite, Hematite, Gibbsite	
	Feed bauxite From Alumina refinary	Gibbsite, Hematite Goethite	Kaolinite, Sillimanite, Zircon
Host Rocks	Lithomarge/clay	Kaolinite, Gibbsite	Goethite, Illite
	Partly altered Khondalite	Gibbsite Kaolinite, Illite	Goethite, Microcline
	Khondalite	Gibbsite, Sillimanite	Almandine, Kaolinite

Detailed mineralogy of bauxite from several parts of world has already been reported[2-4]. Khondalite, the host rock of bauxite, is a quartzo-feldspathic, garnetiferous (almandine) schist/gneissose rock with or without mica /sillimanite (**Table-1**)

Size fraction, in micron	Major Phase	Minor Phase
-1000+500	Gibbsite, Hematite	Goethite
-500+300	Hematite, Goethite	Gibbsite, Muscovite
-300+100	Hematite	Rutile, Goethite
-100+45	Hematite, Goethite	Quartz
-45	Hematite, Goethite	Quartz, Gibbsite

Table 1: Mineralogical variation between host rock and feed bauxite (as brought out through XRD)

Table 2A: Mineralogical variation between classified plants and sample from alumina refinery rejects (as brought out through XRD)

Type of Red Mud	Major Phase	Minor Phase
DG Mud	Rutile, Goethite, Hematite	Gibbsite, Sodalite
DSL Mud	Rutile, Goethite, Hematite, Gibbsite	Bohemite, Sodalite
SM	Hematite, Goethite, Rutile	Sodalite, Gibbsite, Bohemite
WM	Hematite, Goethite, Rutile	Goethite, Gibbsite, Sodalite
MTP	Hematite, Goethite	Sodalite Gibbsite, Rutile, Bohemite

Table 2B: Mineralogical variation between red mud samples collected at different stages from alumina refinery (as brought out through XRD)

DM - Digested Mud; DSM - Desilicated Mud; SM - Settler Mud; WM- Washer Mud, MTP- Mud to Pond.

Minor mineralogical variation between khondalite, partly altered khondalite and lithomarge is recorded (Table-1). Bauxite, the feed to the alumina refinery, may occur in varied colours such as, yellowish, pinkish, grayish, brownish and show vesicular to massive texture and appears mostly in non-pisolitic form. X-Ray diffraction analysis indicated the bauxite to be composed predominantly of gibbsite with minor hematite (**Table-1**) The additional minerals found through Infrared spectroscopy are allophane, boehmite with subordinate diaspore and goethite. Other minor minerals recognised under reflected light microscope and scanning electron microscopes are rutile, ilmenite and zircon along with rare sillimanite, mica and kaolinite booklets. The rejects are broadly of two types, namely undigested sand and red mud. Megascopically, the undigested sand looks black to brick red in colour.

In view of its appearance like sand sized grains, the sample is sometimes termed as 'plant sand'. X-ray diffraction analysis brought out the predominance of hematite, goethite and rutile in this sand. The presence of minor gibbsite was noticed in its courser fraction (>500micron) (**Table-2A**) and quartz in finer fraction (<100 m). When this sample is subjected to physical beneficiation, tabling in particular, the concentrate is found to contain additional minerals like ilmenite and zircon. Red mud is brick red in color, very fine and soils the finger. The size analysis of red mud indicates that its average size is around 3 micron, the d₅₀ passing size is around 8 micron and about 35% by weight of solids contain below 5-micron particles. However, under SEM isolated grains > 20μ (boehmite and rutile / ilmenite) are recorded. The chief constituents of red mud in order of abundance are hematite, gibbsite, goethite, sodalite, boehmite and rutile. The red mud at different stages (DM, DSM, SM, WM, and MTP) looks identical and has more or less similar mineralogical composition. However, a minor variation in their volume percentage at different stages is brought out by XRD (**Table-2B**). Gibbsite dominates in feed bauxite and mud to pond samples. Presence of ilmenite, zircon, sphene in some samples is recorded only under electron microscope.

The refinery product aluminium oxide looks perfectly white and contains only gibbsite.

Metal Distribution in feed, rejects and products

The geochemistry of weathering sequence in bauxite profile has been reported by some workers[5,6] The major, trace and rare earth metal distribution in host khondalite, bauxite fed to alumina refinary, undigested sand, red mud and aluminium oxide (the product) are shown in tables (3to 6). After the alumina is recovered by Bayer's process in the refinery, all other metals originally present in the bauxite are partly disposed into undigested sand and finally into red mud.

Major metals

The host rock khondalite is enriched in two elements such as alumina (29.37%) and silica (54.89) with subordinate iron

(3.46%). During the process of bauxitisation, the alumina content gradually increases from host rock to partly altered khondalite followed by lithomarge. Bauxite derived from host khondalite rocks contains two major metals, namely aluminium (av.: 44% Al_2O_3) and iron (av.: 20% Fe_2O_3). Because of high iron content it appears red to yellow coloured and termed as ferruginous type. When the alumina content is high, the bauxite sometimes appears pink or buff in colour. In the plant sand, the first reject from the refinery is found to be very rich in iron (av.:70% Fe_2O_3) and titanium (av.: 14% TiO2) metals. Some amount of alumina (av.: 8% Al_2O_3) also get released in to plant sand. The bulk red mud contains mainly four metal oxides like ferric oxide, aluminium oxide, titanium dioxide and silicon oxide in varying proportions. High Fe content in the red mud (Fe_2O_3: 51 to 58%) is obvious, because after alumina is digested in to solution the leached residue gets enriched in iron (**Table-3**). The product alumina contains 99.99% of Al_2O_3 and trace of iron, silica and titanium (each 0.01%).

Table 3: Major metal variation in feed, rejects and product

Major Component, in wt%	Host rock	Feed Material	Reject materials		Product
	Khondalite	Bauxite	Plant Sand	Red Mud	Alumina Hydrate
Al_2O_3	29.37	44.23	8.35	15.16	99.99
Fe_2O_3	3.46	20.16	70.89	53.98	0.01
SiO_2	54.89	2.66	1.52	12.13	0.01
TiO_2	1.15	1.99	14.23	3.88	0.01

Minor metals

The minor metals in bauxite of some significance include titanium (TiO_2: 2.2 to 3.00%), phosphorus (P_2O_5: 0.10 to 0.19%), manganese (MnO_2: 0.12 to 0.18) and sodium (Na_2O: 0.15 to 0.37). Potassium, calcium and magnesium are of rare occurrence (max. up to 0.1%). During treatment of bauxite all these elements go into red mud. Minor amount of calcium, phosphorus and manganese is recorded in red mud samples. Although calcium and phosphorus contents are negligible in first three stages of disposal [DM, DSM & SM], the value increases at washer mud (CaO: 1.56%; P_2O_5: 0.32%) and mud to pond (CaO: 2.3%; P_2O_5: 0.4%) sample (**Table- 4A & B**).

Table 4A: Major metal variation (in wt %) in red mud generated at different stages

Code	Al_2O_3	Fe_2O_3	SiO_2	TiO_2
Bulk	15.20	52.70	12.10	4.40
DM	14.80	51.10	12.71	5.20
DSM	15.90	57.65	14.50	4.10
SM	15.83	56.95	14.30	3.60
WM	14.53	51.80	10.70	3.20
MTP	14.73	52.39	8.44	3.30

Table 4B: Minor metal variation (in wt %) in red mud generated at different stages

Code	CaO	V_2O_5	P_2O_5	MnO
Bulk	0.94	0.16	0.23	0.15
DM	0.80	0.21	0.17	0.17
DSM	0.03	0.17	0.13	0.15
SM	0.03	0.15	0.13	0.14
WM	1.56	0.14	0.32	0.18
MTP	2.30	0.16	0.40	0.13

DM - Digested Mud; DSM - Desilicated Mud, SM - Settler Mud;WM- Washer Mud; MTP- Mud to Pond.

Higher calcium is due to addition of lime in the settler as flocculants and the minor amount of phosphorus (P_2O_5, 0.13 to 0.40%) may be from undigested sphene. Manganese content remains more or less similar (MnO, av. 0.1%) in the entire set of samples.

Trace metals

Distribution of trace elements in Indian bauxite is recorded by Banerjee[10]. In the present report the trace metal distribution pattern in the feed and rejects shows following interesting results:

i. The values of Sc, Ni, Sr and Cr increase sequentially from bauxite to plant sand and then to red mud (**Table 5**).
ii. Some metal values like Ga, Cs and Rb deplete from bauxite to plant sand and then increases in red mud. Appreciable Ga (35 ppm) goes with aluminium hydrate
iii. Concentration of many metals like Co, Y, Hf, Ta, Cu, Zr, V, Zn, Nb, Ba, Pb, Th, and U show a rise from bauxite to plant sand and then fall in red mud.
iv. Significant rise in Zr (2074 ppm), Cr (914 ppm), Ba (765 ppm) Ga (137 ppm) and Hf (84 ppm) values in finer fraction (-100μ) of plant sand is recorded. Higher Zr value is supported by concentration of zircon grains in this fraction.
v. The trace metals distributed in red mud samples at different disposal points (**Table 6**) also show some variation. While a few elements like Sc, V and Cr show increasing trend from DGM to MTP, many other elements (Ni, Y, Zr, Nb, Cs, Ba, Ta, Pb, Th and U) show a gradual depletion. However, elements like Cu, Zn, Co, Ga, Rb, Sr, Bi and Hf do not show any trend.

Table 5: Trace element variation in feed, rejects and products

Element, in ppm	Host Khondalite	Feed bauxite	Plant Sand	Red Mud	Alumina Hydrate
Sc	76.94	25.29	57.19	57.59	0.25
Co	13.55	16.18	98.98	24.21	0.01
Ni	68.73	30.39	46.75	53.01	1.65
Ga	64.42	79.15	74.69	91.31	35.26
Rb	2.63	14.33	0.68	5.75	0.07
Sr	12.48	20.45	36.53	43.57	3.87
Y	14.29	8.2	15.58	13.29	0.03
Cs	0.07	0.41	0.05	0.44	0.01
Hf	2.54	8.74	29.83	25.16	0.02
Ta	2.48	2.8	13.6	3.61	0.34
V	400.63	292.75	738.25	517.34	2.16
Cr	265.84	318.44	706.49	739.1	5.14
Cu	116.88	42.72	226.17	105.52	2.06
Zn	100.87	66.96	328.09	101.57	4.15
Zr	61.01	170.54	749.76	279.28	1.04
Nb	38.55	41.7	261.75	54.8	0.35
Ba	174.18	233.94	350.82	287.25	4.01

Pb	40.69	43.83	161.93	71.77	0
Th	41.89	117.63	295.52	175.8	0.08
U	2.80	1.86	6.31	2.82	0.1

ND: Not Detected

Table 6: Trace element variation in red mud generated at different stages

Elements in ppm	DM	DSM	SM	WM	MTP
Sc	48.58	50.42	52.08	66.93	69.93
V	411.61	425.12	425.04	580.67	746.25
Cr	643.33	654.50	759.76	791.55	846.35
Co	33.33	23.95	22.87	19.79	21.14
Ni	60.61	54.84	53.72	49.99	45.89
Cu	90.63	71.31	76.99	184.82	103.87
Zn	113.48	85.19	88.79	133.79	86.58
Ga	99.52	86.71	85.25	91.88	93.18
Rb	5.57	6.08	5.93	5.26	5.90
Sr	49.98	42.28	37.47	40.47	47.67
Y	16.71	14.28	13.66	11.86	9.95
Zr	380.58	286.37	250.88	244.48	234.10
Nb	79.74	58.47	50.93	44.82	40.05
Cs	0.62	0.57	0.46	0.30	0.23
Ba	440.39	389.84	339.78	175.52	90.75
Hf	15.94	82.59	9.83	9.16	8.29
Ta	5.31	4.14	3.39	2.68	2.55
Pb	95.46	83.56	74.29	57.30	48.22
Bi	103.98	109.66	95.64	72.91	38.05
Th	242.37	216.43	184.65	143.65	90.89
U	3.42	3.38	3.21	2.54	1.56

Table 7: Rare earth element variation in feed, rejects and products

Element, in ppm	Host Khondalite	Feed bauxite	Plant Sand	Red Mud	Alumina Hydrate
LREE					
La	73.71	64.81	215.72	112.46	0
Ce	176.52	97.43	498.33	190.82	0.27
Pr	18.76	10.14	53.95	18.01	0.01
Nd	62.17	32.49	184.99	48.06	0.06
Sm	11.92	5.29	31	8.59	0.12
Eu	1.26	1.54	1.66	2.35	0.01
HREE					
Gd	8.45	4.56	18.94	7.16	0.01
Tb	0.75	0.49	1.38	0.73	0
Dy	3.78	2.5	5.82	3.96	0.01
Ho	0.40	0.3	0.65	0.52	0
Er	0.87	0.8	1.53	1.25	0
Tm	0.22	0.12	0.17	0.19	0.01
Yb	1.79	0.93	1.71	1.76	0
Lu	0.21	0.13	0.29	0.23	0

Rare earth metals

Synthesis on the rare earth metal dispersion in the feed and rejects shows following results:

i. Most of the light rare earth and heavy rare earth metal values decrease from bauxite to plant sand and then increase in red mud (**Table 7**). However, Eu, Tm and Yb values gradually fall from feed to plant sand to red mud.

ii. In the finer fraction of undigested sand a rise in cerium value (498 ppm in bulk increases to 638 ppm in <45 μ) is observed. Similarly, most of the HRE element content (expecting Gd and Tb) show enhancement in finer fraction than that of the bulk sample.

iii. The light rare earth and heavy rare earth metals in red mud (excepting Tm) show gradual fall in their values from DM to MTP stage (**Table 8**).

Table 8: Rare earth element variation in red mud generated at different stages

Element, in ppm	DM	DSM	SM	WM	MTP
LREE					
La	168.94	149.93	135.52	66.87	41.05
Ce	252.35	238.86	210.54	157.39	94.96
Pr	27.29	24.29	20.77	10.54	7.15
Nd	73.68	63.27	54.10	30.61	18.64
Sm	13.03	11.54	9.03	6.01	3.35
Eu	3.66	3.20	2.81	1.25	0.82
HREE					
Gd	10.26	9.17	8.46	4.45	3.47
Tb	1.08	0.94	0.78	0.53	0.33
Dy	5.85	4.67	4.23	3.06	2.00
Ho	0.75	0.63	0.50	0.43	0.28
Er	1.65	1.46	1.23	1.12	0.81
Tm	0.29	0.25	0.22	0.17	0.12
Yb	2.26	2.05	1.88	1.60	0.99
Lu	0.30	0.27	0.24	0.24	0.12

DM – Digested Mud; DSM - Desilicated Mud; SM - Settler Mud; WM- Washer Mud; MTP- Mud to Pond.

Recovery of valuable metals from Plant Sand

The authors are in agreement with Rao et al[11] that the pland sand contains lot of valuable metal. For recovery of valuable metals from the plant sand, different conventional physical beneficiation techniques may be employed[12]. The sample was subjected to Tabling and collected the zircon bearing Table Concentrate-I and Ilmenite bearing table concentrate-II and tailings in continuous operation on bench scale. The table concentrate-II was re-tabled to collect the zircon rich concentrate-IIa and ilmenite rich concentrate IIb. The zircon rich concentrates I and IIa were re-tabled and the resulting heavies were subjected to wet high intensity magnetic separation [WHIMS], from which the zircon concentrate was collected as non magnetic product [~ 60% $ZrSiO_4$] and the ilmenite as magnetic product. This magnetic product is mixed with the Ilmenite rich concentrate-IIb and subjected to cell flotation. The flotation concentrate was rich in ilmenite content (~ 40% TiO2).

The table concentrate shows appreciable iron (Fe_2O_3: 67%) and titanium (TiO_2: 26%) along with other metals like Zr, Hf, Nb, Th,

Ta, U and Y. All LRE and HRE elements are enriched in table concentrate product. The magnetic product obtained from WHIMS is rich in iron (Fe_2O_3: 76%) with appreciable titanium (TiO_2: 9%) along with minor enhancement in V, Cr, Rb, Sr while the non-magnetic product was enriched in Zr, Hf, Sc, Zn, Y, and U. All LRE and HRE elements are enriched in non-magnetic fractions.

The flotation concentrate shows highest titanium value while it's tailing gets enriched in iron (Fe_2O_3: 68%). Elements like Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Hf and U values get enriched in the concentrate while value of Sc, V and Cr increases in its tail product. All LRE and most of the HRE elements excepting Gd show higher concentration in flotation concentrate.

Conclusions

Formation of bauxite is due to residual concentration of certain metals like aluminium during chemical weathering of silicate minerals[13,14] from host khondalite. In this bauxitisation process, some metals get depleted and some others get enriched. Due to poor mobility[15], metals like titanium, zircon, hafnium, and niobium are retained in bauxite while a few others like Y, V etc. move with iron and get precipitated in Fe- rich bauxite and laterite.

During then processing of bauxite in Bayer's process, alumina is recovered in the form of sodium aluminate solution while all other minor, trace and rare earth metals get precipitated with iron and discharged in to red mud pond and available therein. Due to intimate association of these metals with iron in the red mud it is difficult to recover some of them through any physical beneficiation techniques. However, some undigested materials, rich in valuable metals are removed as plant sand in the first stage. Following appropriate physical beneficiation process such as tabling, wet high magnetic separation and flotation, the titanium-rich and zirconium-rich minerals, containing several valuable metals in adsorbed state, from plant sand can be recovered. Though trace metals like Ga, Ba, Zn, Sr, Cr, V, Cu etc. are present in the alumina, produced from khondalite hosted bauxite, its superior quality is evidenced from absence any major and minor metals therein.

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INDIAN BAUXITE FROM TWO GEO-ENVIRONMENTS - A COMPARATIVE STUDY

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Abstract

Bauxite capping over Eastern Ghats Group (EGG) and Iron Ore Group (IOG) in Orissa, India show contrasting physical, mineralogical and compositional characteristics. Bauxite over EGG appears as extensive plateau blankets at higher altitude while IOG bauxite occurs as small tabular low-level platforms. The IOG bauxite shows thicker vegetation in contrast to the sparse growth in other type. The EGG bauxite exhibits spongy texture contrary to pisolitic textures shown by IOG bauxite.

Gibbsite is present in both bauxite, but boehmite and minor diaspore are recorded in IOG bauxite. Relict muscovite, sillimanite and kaolinite/illite are noticed in EGG bauxite only. Ilmenite and rutile are present in EGG setup in contrast to leucoxene and anatase in IOG bauxite. Compositional finger print of selective phases indicates the IOG bauxite to be largely of boehmitic type while EGG bauxite is gibbsitic. EGG bauxite is metallurgical grade and IOG bauxite of refractory grade. The bauxite of two setups exhibits different chondrite normalised patterns.

In EGG province, alternate acid and alkali leaching was followed by partial re-crystallization while in IOG province, alkali leaching was followed by multistage precipitation. It is established that the bauxite ore bodies in different parts of India have formed under different geo-environmental conditions.

Key words: East coast bauxite, Iron ore Group, khondalite, Iron ore shale.

Introduction

Bauxite having heterogeneous parentage occurs as tabular aprons in several parts of Orissa, India. Such bauxite forms under different geo-environment by the process of lateritisation, which is generally controlled by mineralogical and geochemical characteristics of the host rock/s on one hand and by climatic and geomorphologic conditions and tectonic framework on the other. Lateritisation involves dissolution and mobilisation of most of the elements of the constituent mineral phases followed by residual concentration of alumina and oxides/ hydroxides of iron and titania. The major and minor rock forming minerals and overall chemical constituents (major, minor, trace & REE) vary widely from one rock type to the other and from one place

to the other. Hence it is likely that the process of lateritisation from initial stage till the transformation and geochemical partitioning of different elements would be different in weathering profiles derived from rocks of different geo-environment.

Our knowledge on entire gamut of process involved in bauxite formation is still not adequate. Bauxite caps are reported over divergent rock types in Orissa and other parts of India as well. There is a lack of comparative study of laterite profiles of various parentages in respect of mineralogical transformation, elemental mobilisation and distribution. In addition, the role of textural and mineral attributes of rocks from different environment in facilitating the lateritisation process is not fully understood.

Many researchers have characterised bauxite through different instrumental techniques. Development of bauxite from different rock through the process of chemical leaching is reported by several workers but the geo-environment in which these are formed is sparsely recorded. Bauxite from two distinctly different parentages widely separated in time and space have been studied. Two bauxite ore bodies: one from south Orissa (Kashipur and Laxmipur) capping over hypo-grade metamorphite rock (Khondalite) of lower-middle Proterozoic age, named as EGG province and Jaldihi and Kusumdih from north Orissa lying over shale (epimetamorphic sedimentary rock) of Banded Iron Formation of upper Proterozoic age referred to herein as IOG province are selected for detail comparison. (Fig. 1).

Geological framework

Rocks of the Eastern Ghats hill ranges (hitherto termed as EGG Province), where the bauxite occurrences are located are considered as a portion of the Precambrian crust in India (Ray, 1967). Recently all embracing consensus on geologic, geotectonic and geochronologic aspects of the Eastern Ghats province reinterpreted it as the Eastern Ghats Mobile Belt (EGMB) of mesoproterozoic age (Sarkar et al., 1998). Commercial grade bauxite is confined to the Eastern Khondalite zone (Ramakrishna et al., 1998) of variable thickness and lithology occurring in the easternmost longitudinal litho-zone covering areas of Koraput, and Rayagada districts of southern Orissa. The rocks comprise an interlayered sequence of the khondalites and the charnockite gneisses of granulite facies. The metamorphites are migmatised/granitised on gala scale.

Bauxite over Iron Ore Group of Rocks (hitherto termed as IOG Province) is reported from north Orissa. Jones (1934) referred the belt as a "*horse-shoe shaped synclinorium*" from its geometric configuration and put them under Iron Ore Series. Other workers later designated the rock assemblages as Noamundi Group, Barsuan Group, Roida Group and so on.

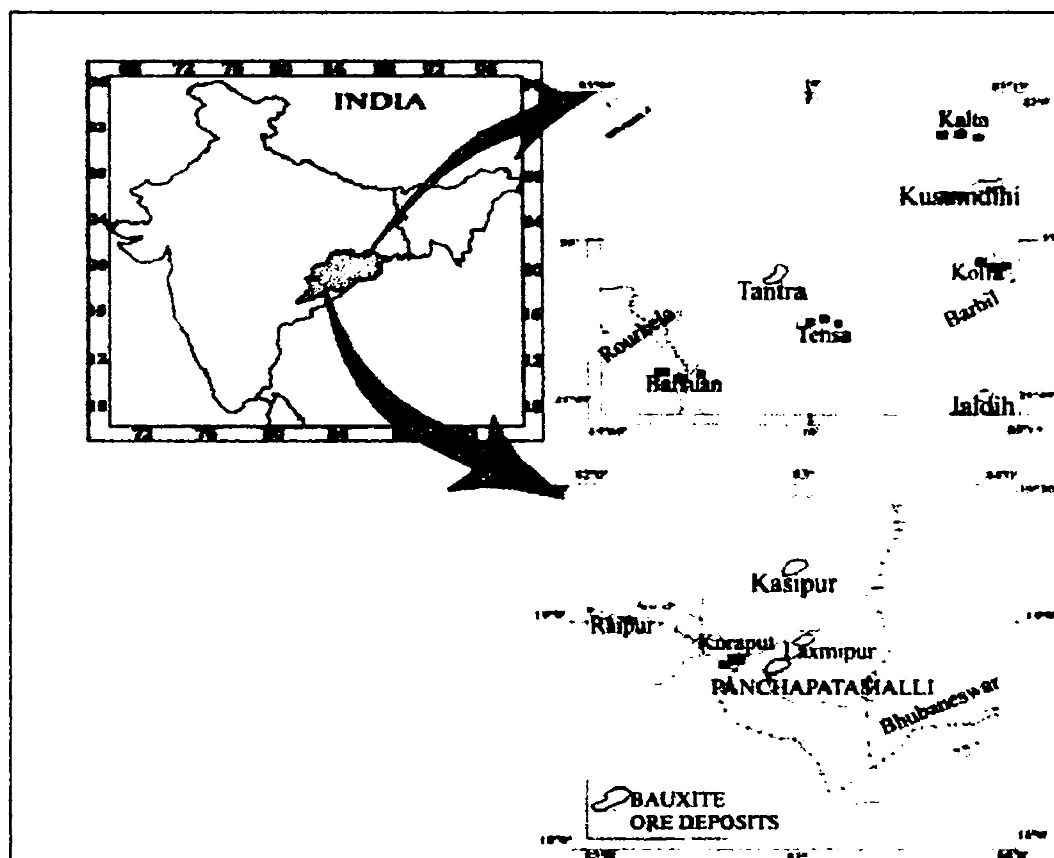


Fig. 1: Map showing location of the two study areas

(Top: Jaldih and Kusumdih in IOG set up; Bottom: Kashipur and Laxmipur in EGG set up)

Bauxite Profile

Bauxite associated with EGG rocks are large tabular and extensive bodies (Fig.2.1) while over IOG rocks it appears as small tabular bodies of limited dimension (Fig. 2.5). Bauxite capping over EGG rocks are located at higher altitude as compared to IOG bauxite bodies.

IOG bauxite cappings have thicker vegetation comprising dense forests while those of EGG cappings are nearly barren of vegetation at plateau tops and have sparse vegetation confined to slopes and valleys. Though the parent rock types of EGG and IOG bauxite deposits are of Precambrian age, the former is older than the later as evidenced from geologic, tectonic and stratigraphic attributes. The general lithotypes in both the provinces are given in Table 1.

The basement rocks of bauxite in the EGG province are khondalite. Thick laterite cappings are observed on flat and gently rolling surfaces at the hill-tops. Generally 20 to 30 m (up to 50m in exceptional cases) thick bauxite blanket occurs below the

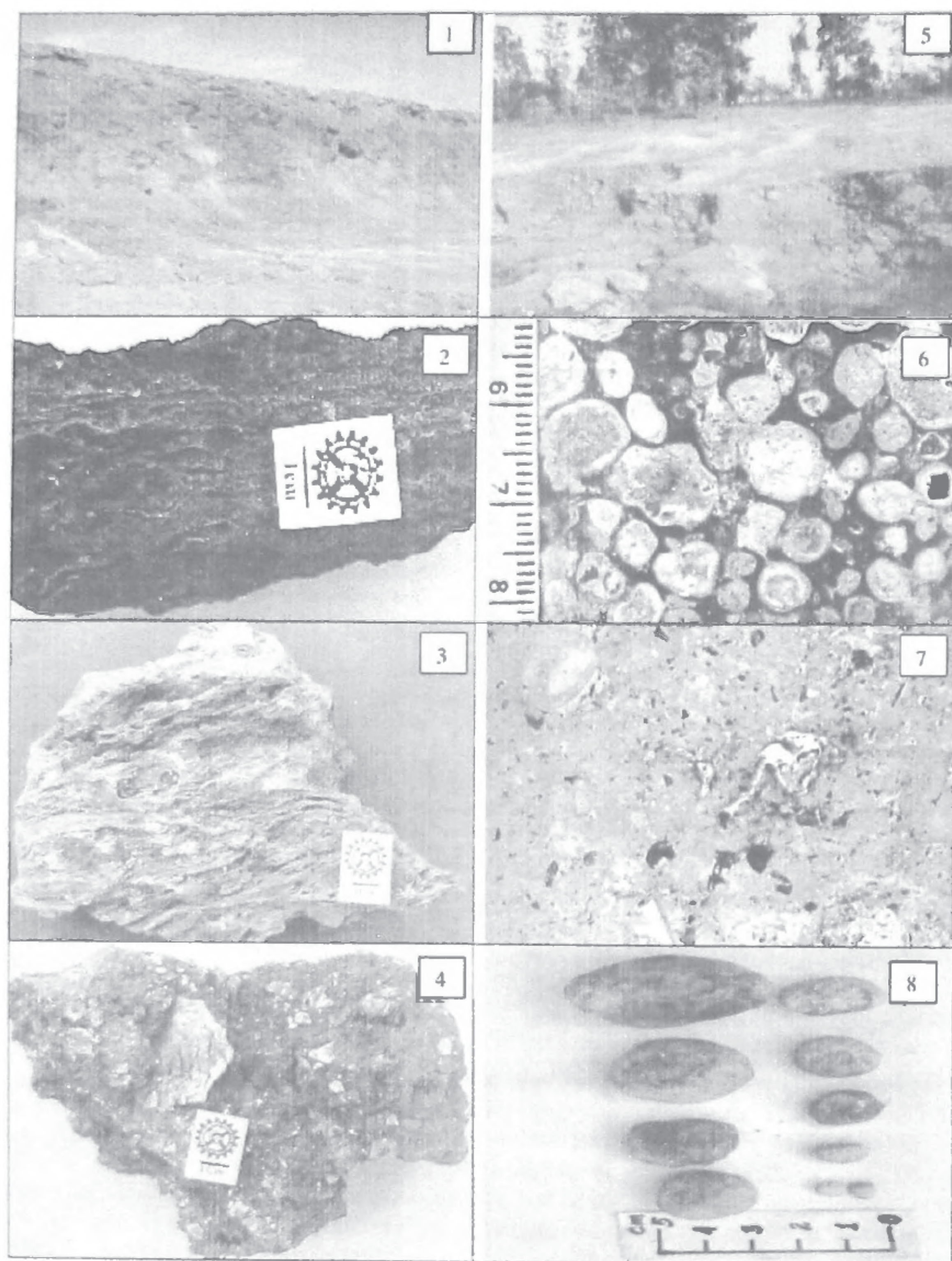


Fig.2: Bauxite profile in EGG (left) and IOG (right) province and typical morphotypes

laterite capping at an altitude of 1000-1500m above mean sea level. From physical appearance, the laterite can be classified into siliceous and ferruginous types. The bauxite below laterite can be grouped into upper zone and lower zone. The bauxite in the upper zone is ferruginous (Fig.2.2), very hard and may be classified into red banded and grayish black type. Bauxite in the lower zone occurs in four different colours, viz. as light pink (Fig. 2.3), yellow, brown and micaceous (Fig. 2.4). Below the laterite-bauxite zone gradationally underlie the weathered parent rock mostly composed of altered khondalite and lithomarge. Lithomarge and altered khondalite show variable thickness (together termed as saprolite zone).

Bauxite in IOG province occurs as a small plateau over iron ore shale flanking the high altitude ridges of iron ore. The major litho-units in an IOG set up from bottom to top are: tuffaceous shales; thin lithomarge zone, massive to non pisolitic red/yellow bauxite (Fig.2.7) in the lower zone and massive buff coloured, pisolitic (Fig.2.6), semi-pisolitic and / non-pisolitic bauxite in the upper zone succeeded by laterite.

Table 1: Generalized profile of EGG and IOG bauxite ore body

EGG Profile	IOG Profile
Laterite (Siliceous & Ferruginous)	Laterite (Siliceous)
Upper bauxite (ferruginous) [Red and black)	Upper bauxite [buff massive, pisolitic, semi- and pisolitic)
Lower bauxite (Pink, yellow, brown and micaceous)	Lower bauxite (ferruginous) (Yellow and red)
Lithomarge	
Altered khondalite	Lithomarge/altered shale
Khondalite	Tuffaceous Shale

Textural Peculiarities

Bauxite-laterite in both the set-ups show some similar and dissimilar texture/microstructure. The EGG bauxite morphologically appears massive, spongy and banded, while distinct pisolitic/semi pisolitic textures are observed in IOG bauxite. It constitutes pisoloids in different shape and size which often get released from bauxite and found floating at hill slope (Fig. 2.8). Cross section of pisoloids show fine concentric lines over silicate nucleus. Similar microstructures are collomorphous, spongy, platy-foliated, island, loose frame-work, tight frame work, reticulate, platy, and porphyroblastic. Dissimilar textures recorded in both the set up are relict, skeletal, stalactitic, oolitic. These findings on textural/microstructural peculiarities support distinct difference in the causative bauxitisation process operative in the geo-environment of the two set ups.

Mineralogical Manifestation

Both the set-ups show contrasting mineralogy through out their profile. Different minerals were identified by combined techniques of microscopy and XRD while their gibbsite content was determined from TGA. Mineralogical details of Parent rock-Saprolite zone and Bauxite-Laterite zone of both the provinces are shown in Table 2 and 3 respectively.

Mineral Chemistry

In-situ composition of different minerals under EPMA confirms the different mineral phases in both the set-ups. Dominance of gibbsite with minor boehmite in EGG bauxite is observed while IOG bauxite is essentially of boehmitic type having minor diaspore. FeO and P_2O_5 content adsorbed within alumina trihydrate/ monohydrate phases are relatively more in bauxite of IOG rocks compared to that of EGG rocks. CoO and rarely NiO, adsorbed within alumina trihydrate/monohydrate phases, are relatively more in bauxite of EGG set up than that of IOG set up.

Geochemical Characteristics

Major chemistry of parent rocks of both the set ups are different. Alumina content in parent khondalite is 42% which is relatively lower than that of shale (47%). Reciprocal silica and iron content is observed in both the set ups (SiO_2 in khondalite: ~26%; shale: ~36%: Fe_2O_3 in khondalite ~24%; in shale ~4%). Chemically, the IOG bauxite is of refractory grade and EGG of metallurgical grade. In other word the former type (IOG) is rich in alumina (Al_2O_3% ~64%) and poor in iron (Fe_2O_3~ 3%) while the later is moderate in Al_2O_3 (~59%) and have relatively higher iron (Fe_2O_3~6%) content. The ferruginous bauxite (upper bauxite) in EGG set up contains higher iron content (Fe_2O_3%: up to 45%) than that of IOG set up (Fe_2O_3%: ~12%). EGG bauxite shows higher titanium value than IOG bauxite. Both the bauxite types may have negligible minor elements like potassium, calcium, magnesium, manganese and phosphorous.

Some elements like Co, Ni, Zn, Cs, Ba, Ta and U show higher value in khondalite than shale. The bauxite of lower bauxite zone of EGG shows higher value in respect of eleven constituents like Co, Ni, Cu, Zn, Rb, Sr, Nb, Cs, Ba, Ta and U than of IOG. Ferruginous bauxite in upper zone of EGG bauxite shows higher value in ten elements like Co, Ni, Cu, Zn, Sr, Y, Cs, Ba, Ta and U while IOG bauxite show relatively higher value in rest of ten elements analysed. Khondalite constitutes higher level of Light Rare Earth Elements (LREEs), excepting Eu, than shale. In contrast, the shale has higher Heavy Rare Earth Elements (HREEs), excepting Gd and Tb, compared to khondalite.

The REE value in general shows a gradual depletion from basement shale to lower bauxite and upper bauxite. Conversely, REEs in EGG set up deplete in lower bauxite from the parent rock and show enrichment in the upper bauxite (ferruginous type). The normalized REE pattern of EGG bauxite is distinctly different from that of IOG bauxite

Table 2: Mineralogical characteristics of litho types in parent rock-saprolite zone

Zone	Litho-types	Major mineral	% of Gibbsite	Minor mineral
EGG Province				
Saprolite	Lithomerge	Kaolinite, Gibbsite	15	Goethite , Illite
	PLK	Gibbsite, Kaolinite, Illite	11	Goethite, Microcline
Parent rock	Khondalite	Quartz, Feldspar, Silimanite	-	Almandine, Kaolinite
IOG Province				
Saprolite	Lithomarge	Kaolinite, Hematite, Goethite	20	Gibbsite, Quartz
	Altered shale	Kaolinite, Hematite	15	Gibbsite
Parent rock	Shale	Kaolinite, Goethite	-	Hematite

Table 3: Mineralogical characteristics of different lithotypes from bauxite- laterite zone

Zone	Litho-types	Major mineral	% of Gibbsite	Minor mineral
EGG Province				
Laterite	Siliceous	Gibbsite, Quartz	27	Goethite, Hematite, Kaolinite
	Ferruginous	Gibbsite, Goethite, Hematite	16	Quartz, Kaolinite
Upper Bauxite	Red	Goethite, Hematite, Gibbsite	34	-
	Black	Hematite, Gibbsite	51	-
Lower Bauxite	Pink	Gibbsite, Goethite	72	Kaolinite, Muscovite,
	Yellow	Gibbsite	71	Muscovite
	Brown	Gibbsite, Goethite	72	Hematite, Silimanite
	Mica.	Gibbsite, Muscovite	42	Kaolinite
IOG Province				
Laterite	Siliceous	Kaolinite, Goethite, Gibbsite	25	Quartz, Hematite.
Upper Bauxite	Massive	Gibbsite, Boehmite, Diaspore	31	Anatase
	Pisolitic	Gibbsite, Boehmite	68	Anatase
	Semi pisolitic	Gibbsite	62	-
Lower Bauxite	Red	Gibbsite , Boehmite , Hematite	59	Anatase (a)

while the former shows sloppy pattern the later is of flat type (**Fig.3**). All litho units in EGG and IOG show negative Ce anomaly. Similarly all the units of IOG show positive Eu anomaly but in EGG only parent rock and its altered equivalent show strong negative Eu anomaly while its bauxite derivatives show weak positive Eu anomalies

Discussion on Environment of Bauxite formations

Mineralogical observations of bauxites and their corresponding geochemistry are supportive of interpreting the bauxite-laterite of EGG and IOG province of in-situ chemical weathering. The field and laboratory evidences supporting an autochthonous origin. evidently indicate their development under different geo-environmental conditions. The variation in mineralogy is indicative of phase reconstitution affected during weathering processes. Rao et al. (1995) have reported heaps of silica sand reposed amidst the Panchpatmali bauxite hills that situation in these locales is quite evident as large volume of silica is precipitated in these open space areas as saccaroidal quartz. after their removal through dissolution and transportation from the parent rock. The sudden increase of silica in the upper surface zone is only related to present-day weathering and due to some water consuming vegetation. Presence of diaspore in IOG province indicates higher degree of dehydration while ilmenite has undergone leucoxenisation during weathering. Occurrence of titanium as co-precipitate of alumina in ooloids indicates its authigenic nature.

The physico-chemical factors that generally favour the process of bauxitisation is well established. The steps of bauxitisation in both the geological set ups are as follows:

EGG set up

1. The aluminium silicate minerals such as garnet, sillimanite, muscovite feldspar etc. present in the parent rock 'khondalite' converted in to kaolinite in the second stage through alternate acid and alkali leaching.
2. Gradually, the alumina gets residually concentrated and formed the lower bauxite zone.
3. The iron present in the parent rock gets remobilized subsequently and precipitated in the weak plane above bauxite zone and become ferruginous. Though this zone is not very regularly persisting, it is considered as upper bauxite zone.
4. The resistant minerals like ilmenite, rutile and zircon do not undergo any sort of leaching as observed from their similar optical properties in both khondalite and bauxite.

IOG set up

1. As originally the parent rock 'shale' constitutes kaolinite, the second stage of EGG set up must be missing here.
2. As chemical weathering initiates, silica present in kaolinite/allophane gets released during dissolution in the form of mono-silicic acid only.

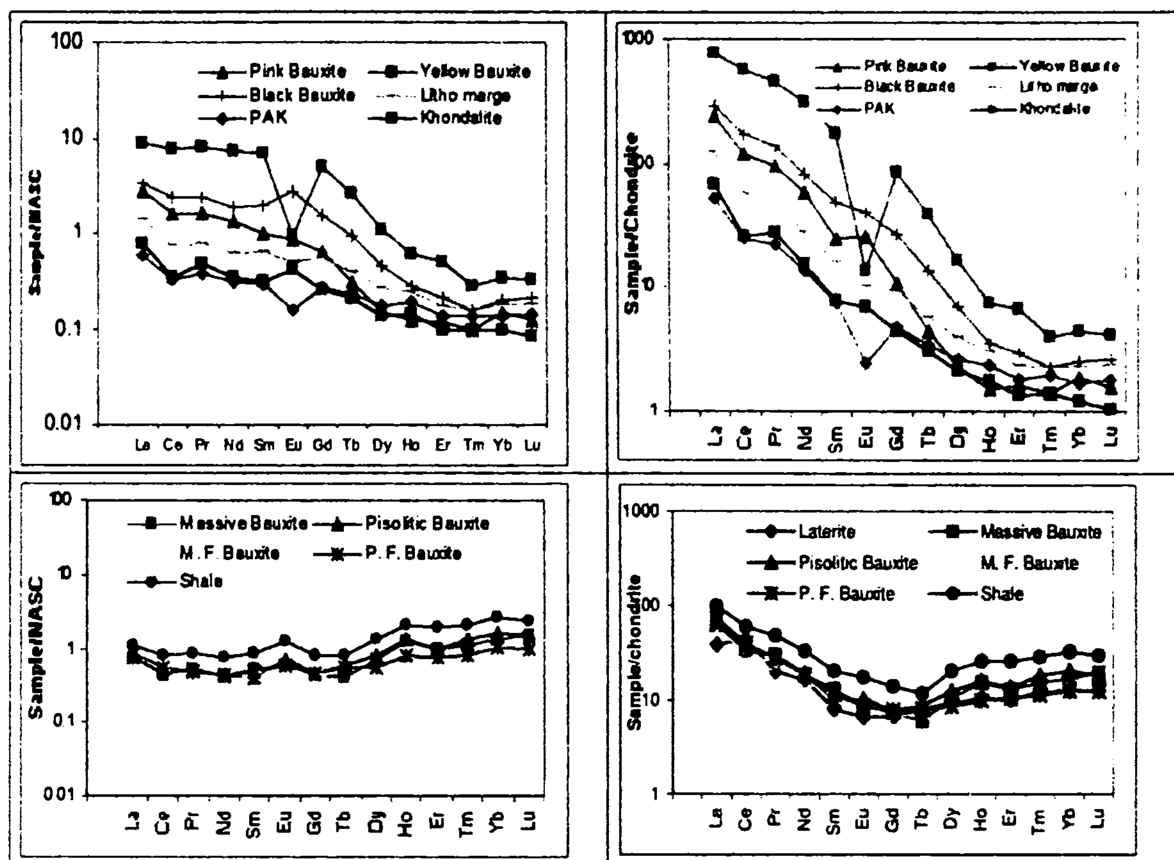


Fig. 3: REE Normalised patterns of samples from different litho units from EGG (top) and IOG set ups (bottom). Left: NASC normalized; Right: Chondrite normalised.

Beckwith and Revee (1969) noticed the dissolution of quartz to be intense in an acidic environment and active in the presence of sesquioxides.

3. Interestingly, the alumina after its formation gets leached under strong acidic environment and dissolved alumina rich fluid gets precipitated in multistage over a shale nucleus and thus develops pisolitic texture.

Conclusions

Comparative study of bauxite occurrences in two different geological set ups (EGG & IOG) from Orissa, India was undertaken. Different parameters such as field disposition, profile variation, microstructural-mineralogical and geochemical characteristics of parent rock and their bauxite derivatives were thoroughly examined and interpreted in terms of their formation under different geo-environments during the process of lateritisation. Forgoing discussion establishes the following conclusions:

(i)Tabular bodies of bauxite in EGG sector are quite extensive and poor in vegetation while in IOG set up these are of smaller dimensions and thickly

vegetated. (ii) In EGG bauxite the basement rock is overlain by thick bauxite zone (lower) followed by ferruginous bauxite (upper) which is enveloped by thick laterite horizon. Both lower and upper bauxite zones are gradational. The parent shale in IOG set up is overlain by moderately thick bauxite grading over each other with a thin ferruginous bauxite zone followed by thin laterite capping. (iii) EGG bauxite are mostly spongy and occur in various shades of colours such as pink, brown, red and black while the IOG bauxites are mostly buff and red coloured and show pisolitic to semi pisolitic texture. The bauxite from both the set up show many similar texture/microstructure and a few dissimilar texture such as relict type in EGG bauxite and oolitic, stalactitic in IOG bauxite. (iv) The khondalite in EGG set up shows a complex mineralogy having quartz, feldspar, garnet silimanite, muscovite and zircon while shale constitutes kaolinite and goethite in different proportion. Khondalite is overlain by a thick saprolite zone while this zone is very thin and may be absent in IOG set up. Dominating mineral in EGG bauxite are gibbsite, boehmite, ilmenite, goethite and hematite while gibbsite, boehmite, diaspore, anatase, leucoxene are observed in IOG bauxite. (v) Generally the EGG litho-units have higher level of chalcophile and siderophile elements but poor in lithophile elements. These have also relatively higher concentration of LREE while all HREE values are high in IOG. The bauxite of two set ups broadly exhibit different NASC/chondrite normalized pattern. (vi It may be surmised that in EGG province large scale leaching (alternate acid and alkali), was followed by partial recrystallisation while in IOG province strong acid leaching was dominant followed by multistage precipitation. Comparison of mode of occurrence and nature of vegetation between two bauxitic provinces of Orissa, India along with their physical attributes, mineralogical and geochemical characteristics strongly suggest their formation under two different geo-environmental conditions.

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Plasma Reduction Process to Minimise Bauxite Residue

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Abstract

Bauxite of Indian origin typically contains 40 – 50 % Al_2O_3, 20 – 28 % Fe_2O_3, 3 – 10 % TiO_2, 4 –10 % SiO_2, 20 –30% LOI and other associated oxides in minor quantities. Due to the higher percentage of Fe_2O_3 in bauxite, generation of Bauxite Residue (or Red Mud), which is costly and problematic to manage, is substantially increased for these bauxites in the Bayer process. In view of this, the recovery of the iron content in bauxite by Plasma Reduction prior to the Bayer process is an interesting option. In this study, laboratory scale simulations have been made to reduce the Fe_2O_3 content in bauxite using the Plasma Reduction process where metallic iron is recovered. The iron produced by this process contains around 85.5% Fe with 85% recovery. The slag rich in alumina and residual iron in the form of FeO can be fed to the Bayer process for the production of alumina.

Key words: Plasma smelting reduction; Arc Plasma smelting reactor; iron from bauxite; Alumina.

1. Introduction

The conventional process for alumina production employing the well-established Bayer Process generates large quantities of Bauxite Residue (or Red Mud) the storage of which is a concern to the alumina industry and the communities in which they operate. So far, outside of some niche applications, no commercial technology has been developed for bulk utilisation of Residue. Utilisation of Bauxite Residue (Red Mud) has been generally limited to either laboratory or pilot scale simulations. However, significant research effort globally is being applied to address this challenge through the application of novel technologies. One such unique and state-of–the-art process is the plasma reduction process which envisages the reduction of iron oxide present in bauxite prior to being fed to the Bayer Process for the extraction of alumina. [1-5]

Bauxite of Indian origin typically contains 40 – 50 % Al_2O_3, 20 – 28 % Fe_2O_3, 3 – 10 % TiO_2, 4 –10 % SiO_2, 20 –30% LOI and other associated oxides in minor quantities. For the production of one tone of alumina, 1 to 2 tonnes of residue is generated out of 2 to 3 tonnes of bauxite. It is now a clear research challenge to reduce to a minimum the percentage of iron oxides present in bauxite prior to bauxite being refined into alumina in the Bayer process. The present work is directed towards this result, and a suitable laboratory scale process has been developed. By employing this process, it has been possible to reduce the bauxite iron oxide content by 85%, and the metallic iron produced contains around 85% Fe. The alumina rich slag produced can be fed to the Bayer process for alumina production.

2. Raw Materials

A Bauxite of Indian origin was the principal raw material for the study. The mineralogical composition and chemical analysis of the bauxite are furnished in Figure 1 and Table 1 respectively. The other raw materials used for the study were aluminium metal (Commercial grade). Hydrogen gas (99.9%) and Argon gas. Figure 1 shows the mineralogical composition of bauxite indicating $Al(OH)_3$ and Fe_2O_3 as major phases as shown in the XRD peaks.

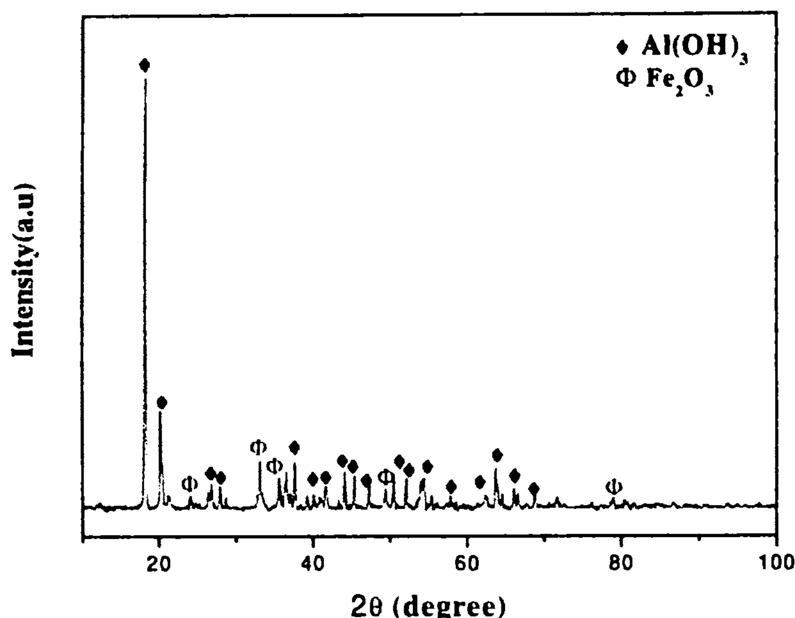


Figure 1. Mineralogical Composition of Bauxite of Indian Origin

Table 1: Typical Chemical Analysis of Indian Bauxite

Input Material	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	LOI
Indian Bauxite (%)	47.74	13.60	9.81	1.0	27.56

3. Experimental

Smelting studies were carried out in a 35 kW dc extended transferred arc plasma reactor. The reactor is basically a pot type. with zircon coated graphite crucible as the furnace hearth. which is thermally insulated by bubble alumina. Graphite electrodes are arranged in a vertical configuration. The bottom electrode (anode) is kept stationary and the top one (cathode). with an axial hole for feeding the plasma forming Argon gas. is actuated by a rack and pinion mechanism for arc stabilization. The hearth is provided with a graphite spout to tap both metal and slag. A schematic of the reactor is given in Figure 2.

The flow of argon gas was regulated to 1.0 L/minute throughout the experiment. An average arc voltage of 50 V and 250 amperes current were maintained during the experiment. The temperature observed in the plasma reactor was 1400-1600 °C. Along with the Argon gas, Hydrogen gas was fed at the rate of 5 L/min acting as the reductant for the iron oxide present in bauxite.

Dry bauxite (1 mm size) along with aluminium metal was charged to the reactor. The amount of reductant was kept at 20%, the basicity was varied from 0.25 to 0.5 and the reduction time was varied from 25 to 35 minutes. The plasma power input was maintained at 15 kW throughout the study. It is observed from the experimental data that the maximum iron recovery obtained is 85% from 1 kg of dry bauxite under the following conditions: reductant: 20 %, basicity: 0.25, smelting time: 25 min, and Plasma Power input:15 kW. The aluminium metal used in the study acts as a co-reductant and facilitates the reduction process. The reduction process is also facilitated by the presence of carbon present on the electrode tips and helps to some extent to produce carbonaceous gases in the process. To nullify the effect of these carbonaceous gases, the aluminium metal is used as a co-reductant. It is well known that the alumino-thermic process is highly exothermic and more reactive than carbon. Therefore, in the reduction process, aluminium predominates over carbon and suppresses the production of carbonaceous gases.

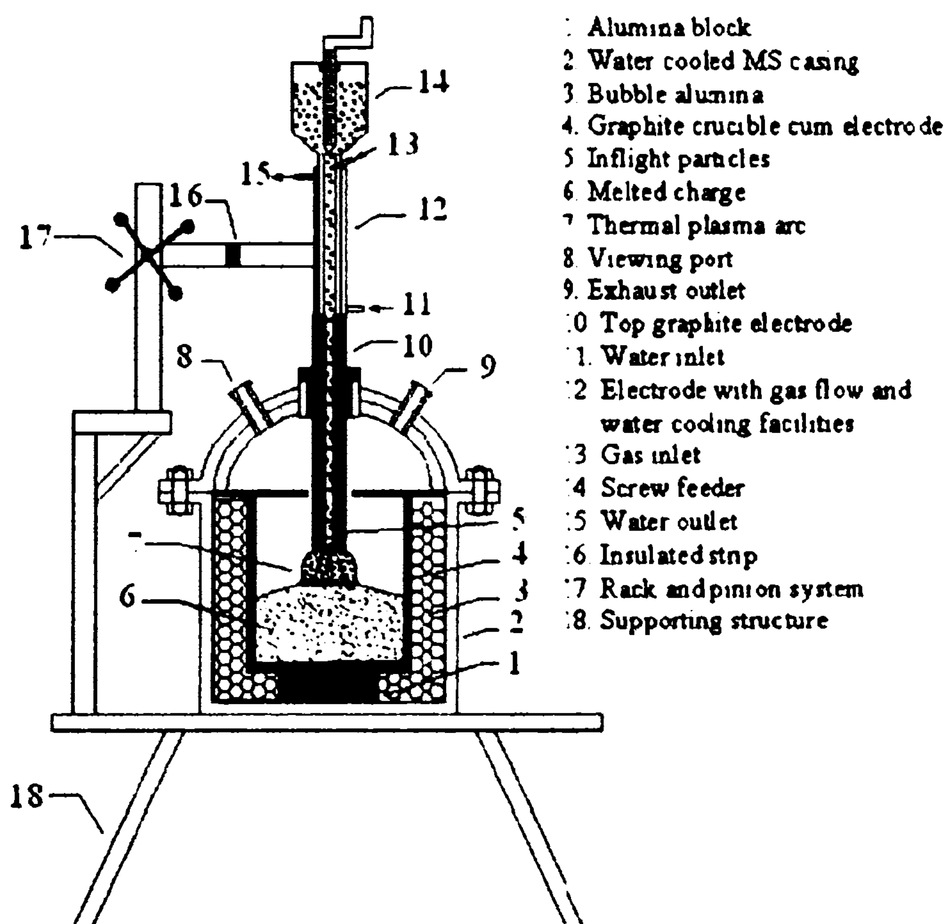


Figure 2. Schematic diagram of extended arc thermal plasma reactor. [6]

3.1 Experimental procedure

Initially bauxite, aluminium metal and dolomite / limestone / fluorspar (flux) powder of required composition were thoroughly mixed and charged inside the graphite crucible. Argon gas was used as plasma gas and was passed through the top electrode at a rate of 1 L/min. The arc was struck and the current of 250 amperes was maintained with an arc voltage of about 60 volts. The plasma arc was continued for 20 to 30 minutes to complete the chemical reaction. The temperature of the molten bath was measured by using a Minolta optical pyrometer. After the molten melt is obtained, the hydrogen gas is fed along with the argon at the rate of 5 L/min. At the end of the smelting, the tap hole was opened and the molten pig iron and slag were allowed to cast in graphite mould. The flow chart of the process is furnished in Figure 3.

FLOW CHART

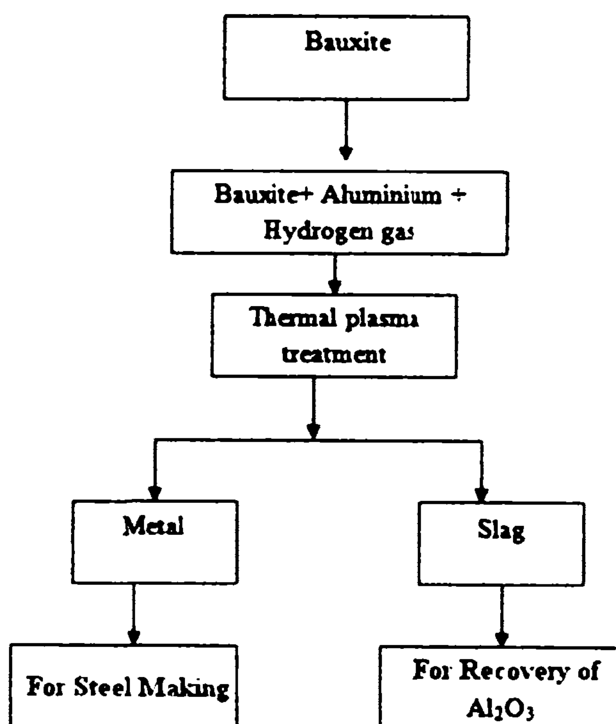


Figure 3. Process Flow Chart.

4. Results and Discussion

About 200 g of Indian Bauxite was taken for Hydrogen Plasma Smelting studies. The bauxite was crushed and ground to -100 mesh and mixed with 20 g of metallic aluminium powder. Then granules of 1 - 6 mm size were prepared by adding 10% water to the powder sample. Granules were dried in an Oven at 120 °C for 6 hrs. Then the dried granules were reduced by Hydrogen Plasma with a flow rate of 8 L / min of Hydrogen gas for a period of 25 min. After the experiment was over, the reduced samples were cooled

and collected separately for metal and slag. The samples were then analyzed by XRD and for Chemical Composition. The chemical composition of metal and slag are given in Tables 2 and 3 respectively. The XRD results for both metal and slag are given in Figures 4 and 5 respectively.

The smelting reduction process takes place by Hydrogen plasma at a higher temperature of 1600°C in Hydrogen Plasma Smelting Reactor. The metallic aluminium powder used in the process acts as an initiator. It is observed that the rate of reaction is increased substantially by using metallic aluminium powder. It may be due to the metallic aluminium powder acting as a better reductant in association with Hydrogen Plasma and facilitates the reaction kinetics. In the process, iron oxide present in bauxite is reduced to metallic iron. At the higher temperature of 1600°C, both metal and slag gets separated.

Table 2. Chemical Composition of Metal.

Sample	Fe	Al	Si	Ti
Metal (%)	85.5	1.25	3.00	1.58

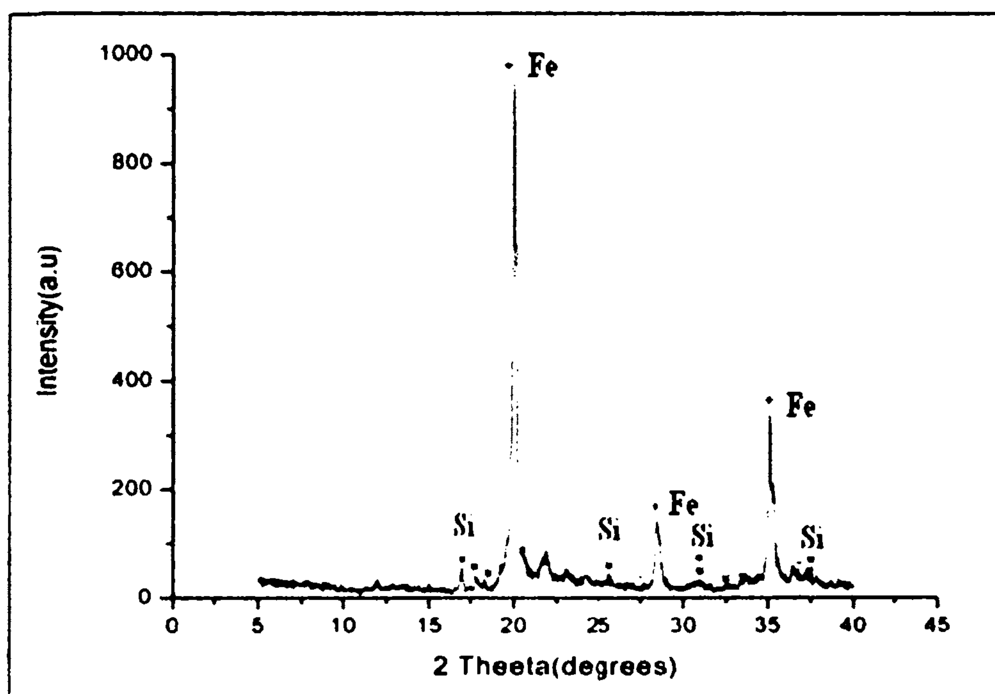


Figure 4. XRD Analysis of Metal.

Table 3. Chemical Composition of Slag.

Sample	Al_2O_3	FeO	CaO	SiO_2	TiO_2
Slag (%)	65.12	2.75	1.09	4.34	2.19

3.1 Experimental procedure

Initially bauxite, aluminium metal and dolomite / limestone / fluorspar (flux) powder of required composition were thoroughly mixed and charged inside the graphite crucible. Argon gas was used as plasma gas and was passed through the top electrode at a rate of 1 L/min. The arc was struck and the current of 250 amperes was maintained with an arc voltage of about 60 volts. The plasma arc was continued for 20 to 30 minutes to complete the chemical reaction. The temperature of the molten bath was measured by using a Minolta optical pyrometer. After the molten melt is obtained, the hydrogen gas is fed along with the argon at the rate of 5 L/min. At the end of the smelting, the tap hole was opened and the molten pig iron and slag were allowed to cast in graphite mould. The flow chart of the process is furnished in Figure 3.

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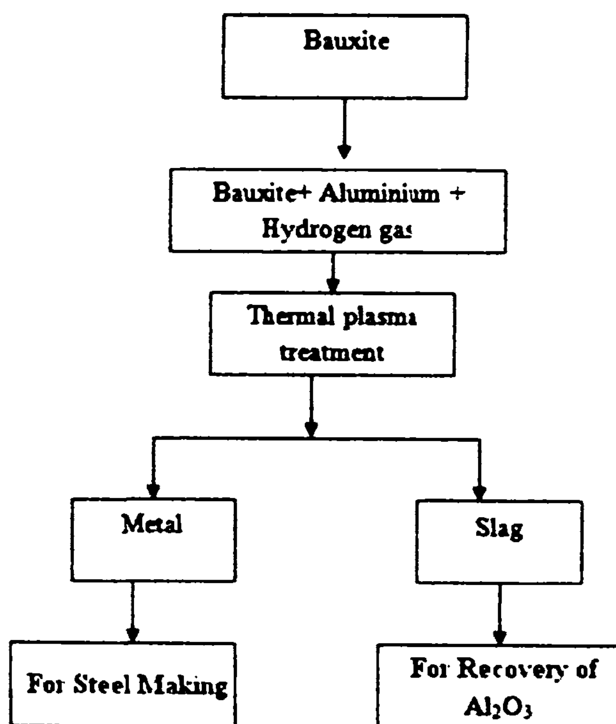


Figure 3. Process Flow Chart.

4. Results and Discussion

About 200 g of Indian Bauxite was taken for Hydrogen Plasma Smelting studies. The bauxite was crushed and ground to -100 mesh and mixed with 20 g of metallic aluminium powder. Then granules of 1 - 6 mm size were prepared by adding 10% water to the powder sample. Granules were dried in an Oven at 120 °C for 6 hrs. Then the dried granules were reduced by Hydrogen Plasma with a flow rate of 8 L / min of Hydrogen gas for a period of 25 min. After the experiment was over, the reduced samples were cooled

and collected separately for metal and slag. The samples were then analyzed by XRD and for Chemical Composition. The chemical composition of metal and slag are given in Tables 2 and 3 respectively. The XRD results for both metal and slag are given in Figures 4 and 5 respectively.

The smelting reduction process takes place by Hydrogen plasma at a higher temperature of 1600°C in Hydrogen Plasma Smelting Reactor. The metallic aluminium powder used in the process acts as an initiator. It is observed that the rate of reaction is increased substantially by using metallic aluminium powder. It may be due to the metallic aluminium powder acting as a better reductant in association with Hydrogen Plasma and facilitates the reaction kinetics. In the process, iron oxide present in bauxite is reduced to metallic iron. At the higher temperature of 1600°C, both metal and slag gets separated.

Table 2. Chemical Composition of Metal.

Sample	Fe	Al	Si	Ti
Metal (%)	85.5	1.25	3.00	1.58

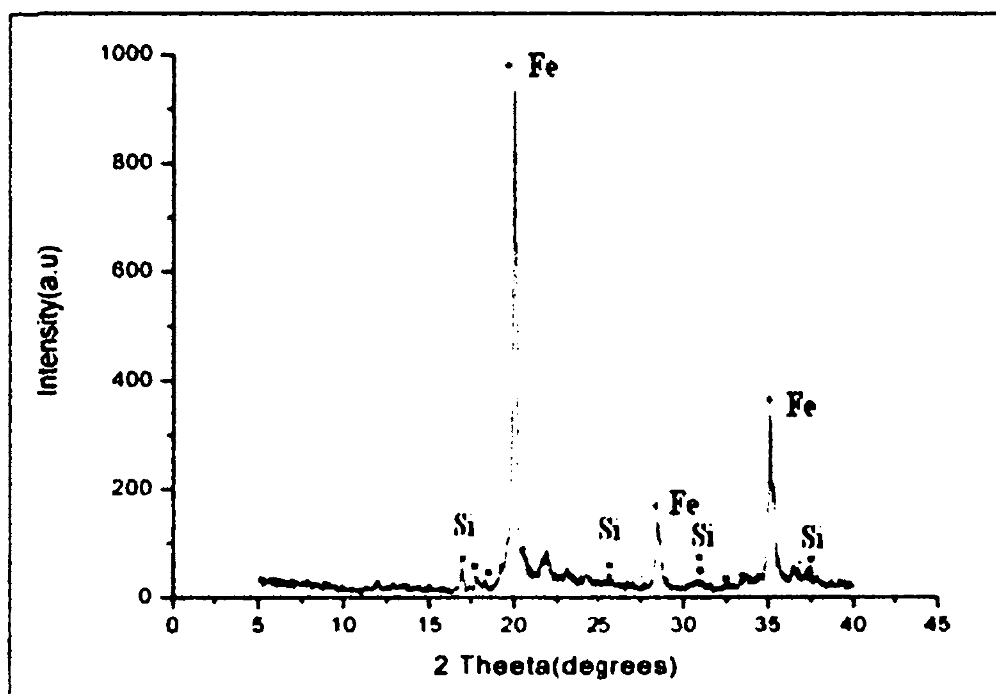


Figure 4. XRD Analysis of Metal.

Table 3. Chemical Composition of Slag.

Sample	Al_2O_3	FeO	CaO	SiO_2	TiO_2
Slag (%)	65.12	2.75	1.09	4.34	2.19

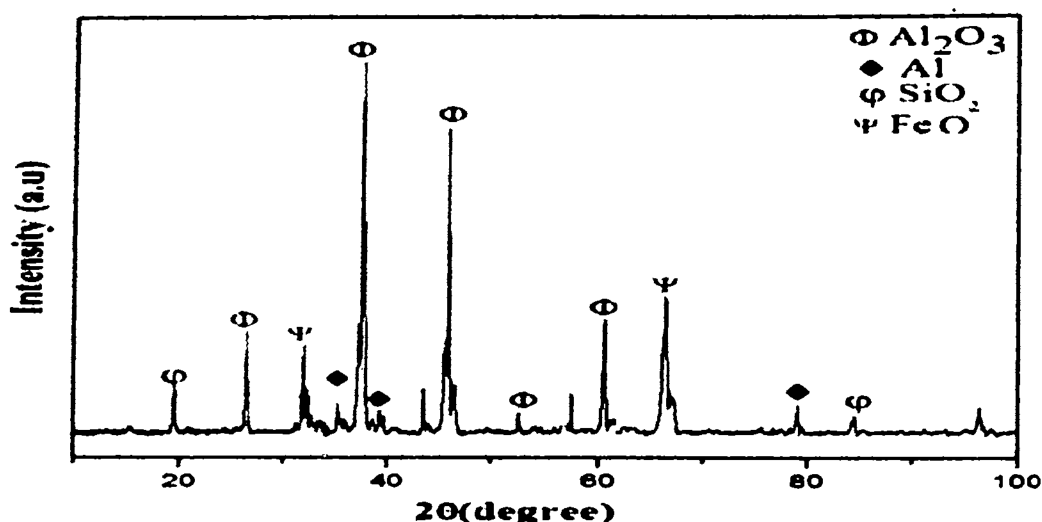
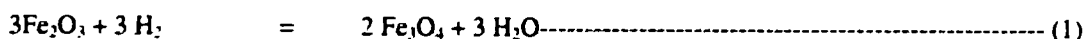


Figure 5. XRD Analysis of Slag.

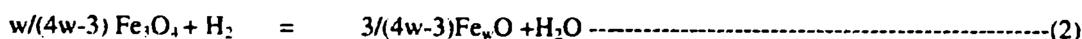
From the above experimental findings it is observed that the iron produced by this process contains around 85.5% Fe with around 85% recovery.

5. Reaction Mechanism

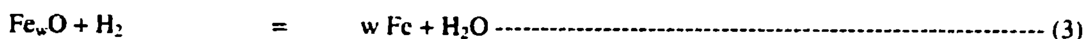
There is no doubt that hydrogen can be used as a reducing gas in smelting reduction processes. A careful analysis of the literature shows that iron oxides can be reduced by hydrogen gas and in this context, a series of relevant reactions taking place in the process are given below [7-8].



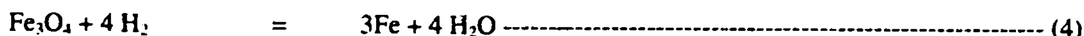
$$3Fe_2O_3 + 3H_2 = 2Fe_3O_4 + 3H_2O \quad (1)$$



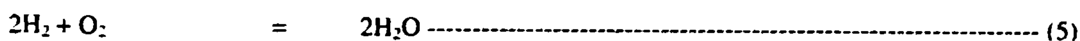
$$w/(4w-3)\,Fe_3O_4 + H_2 = 3/(4w-3)Fe_wO + H_2O \quad (2)$$



$$Fe_wO + H_2 = w\,Fe + H_2O \quad (3)$$



$$Fe_3O_4 + 4H_2 = 3Fe + 4H_2O \quad (4)$$



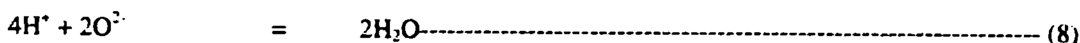
$$2H_2 + O_2 = 2H_2O \quad (5)$$



$$2Fe + O_2 = 2FeO \quad (6)$$



$$4H + O_2 = 2H_2O \quad (7)$$



$$4H^{+} + 2O^{2-} = 2H_2O \quad (8)$$

6. Conclusion

From the above experimental findings it can be concluded that it is possible to produce pig iron containing 85.5% Fe with 85% recovery from bauxite of Indian origin by employing the Hydrogen

Plasma Smelting process. The result obtained in the present investigation seems promising. and may be an option to minimize Bauxite Residue generation in Alumina Refineries.

Further studies are needed to establish higher reduction efficiencies for the iron oxide present in bauxite.

7. Acknowledgement

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PRODUCTION OF GREEN STEEL FROM RED MUD: A NOVEL CONCEPT

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Keywords: Bauxite1, Red mud2, Hydrogen Plasma Smelting3, Green Steel4, Water5

Abstract

Red mud of Indian origin contains around 55% plus of Fe_2O_3 and is considered as a hazardous waste for the alumina industry. For production of one tone of alumina employing the Bayer's Process, around two tones of red mud is generated from three tones of Bauxite. Conventional process of steel making is not devoid of environmental pollution. In the present investigation, efforts have been made to produce steel from red mud by adopting reduction roasting, magnetic separation and hydrogen plasma smelting route. Magnetic fraction, containing enriched iron oxide and minimal content of alumina, is produced following the first two stages which is then subjected to hydrogen plasma smelting process for production of steel. This novel concept follows a green path way for production of steel free from pollution and is termed as green steel. Further, the only by-product that is produced in the process, is water, which is eco-friendly and recyclable.

Introduction

When bauxite is digested with caustic soda by application of time tested Bayer's Process, red mud, a hazardous waste material, is generated in the order of two tones of red mud per one tone of alumina produced. The worldwide alumina production is around 58 million tones in which India counts for 2.7 million tones. India produces around 5.4 million tones of red mud per annum from its various alumina refineries.

The Indian aluminum sector is characterized by large integrated players like HINDALCO, NALCO and the newly started Vedanta Alumina Ltd. The other alumina producers include INDAL, BALCO and MALCO. There are only three main primary metal producers in the sector namely BALCO, NALCO and HINDALCO.

Application of Red Mud for production of different value added items like Portland cement [1] [2], bricks & blocks, tiles, paints & pigments, soil amending agents, fiber reinforced polymer composites for building materials as wood substitutes [3] etc., have been tried out by many researchers throughout the world. However these applications have resulted in partial utilization of red mud and bulk utilization of red mud still remains as a challenge before the global scientific community. Since iron constitutes as a major ingredient of red mud amounting to around 53.6%, the scope of its recovery for production of pig iron is considered as a scientific& technological challenge. Efforts have been made for production of pig iron from NALCO red mud by application of plasma smelting technology [4].

Since the processes so far developed for production of pig iron employing plasma smelting technology was not devoid of environmental pollution, the efforts were directed for production of Green Steel by using Hydrogen Plasma Smelting Technology, considered as a novel and state of the art technique and more so free from environmental hazards. The only by-product that is produced in the process is water which can be recycled for meeting process requirements especially during scale up of the operation. The process is novel and unique in character and is 100% eco-friendly.

Raw Materials

The principal raw material employed for the process was the red mud of Indian origin having the following specification as presented in Table 1. The other raw material used was hydrogen gas with 99.9% purity.

Table 1. Typical Composition of Indian Red Mud

Input Material	Fe_2O_3	SiO_2	TiO_2	Al_2O_3	Na_2O	MgO	CaO	LOI
Indian Red Mud	53.6	18.9	2.20	4.88	8.29	0.21	0.54	9.30

Experimental

Efforts have been made to produce green steel from red mud by adopting (i) reduction roasting technique followed by wet magnetic separation and (ii) smelting of the magnetic fraction rich in iron oxide using hydrogen plasma smelting reactor. The process flow diagram is given in Figure 1.

Reduction Roasting Followed by Magnetic Separation Technique

Red mud in the form of cake containing 53.6% Fe_2O_3 was crushed, ground to -150μ size and mixed with -150μ coke breeze powder containing 65% fixed carbon in the required proportions. The mixture was granulated with 12% water in a disc pelletizer. The granules were then mixed with -2mm coke breeze and charged into the Down Draft Pan Sintering unit for reduction roasting (Figure 2).

A 10 x 10 x 310 mm laboratory-scale pan sintering was used in the experiments. About 50g of charcoal pieces were put on the top of the pan sintering unit for ignition. The bed height was maintained at 300-310 mm. The slow down-draft suction was initially applied for a minute to promote uniform ignition before the draft was increased to the required level. The sintered product was ground to -75μ in a ball mill and then subjected to low intensity wet magnetic separation. The wet magnetic separation was carried out on a low-intensity (2000gauss) magnetic drum separator. The slurry was pumped into the drum at a rate of 300-400cc/minute. The drum speed was maintained at 45rpm. Magnetic and nonmagnetic fractions were collected separately, and then dried, weighed and analyzed for iron content. The results are summarized in Table 2.

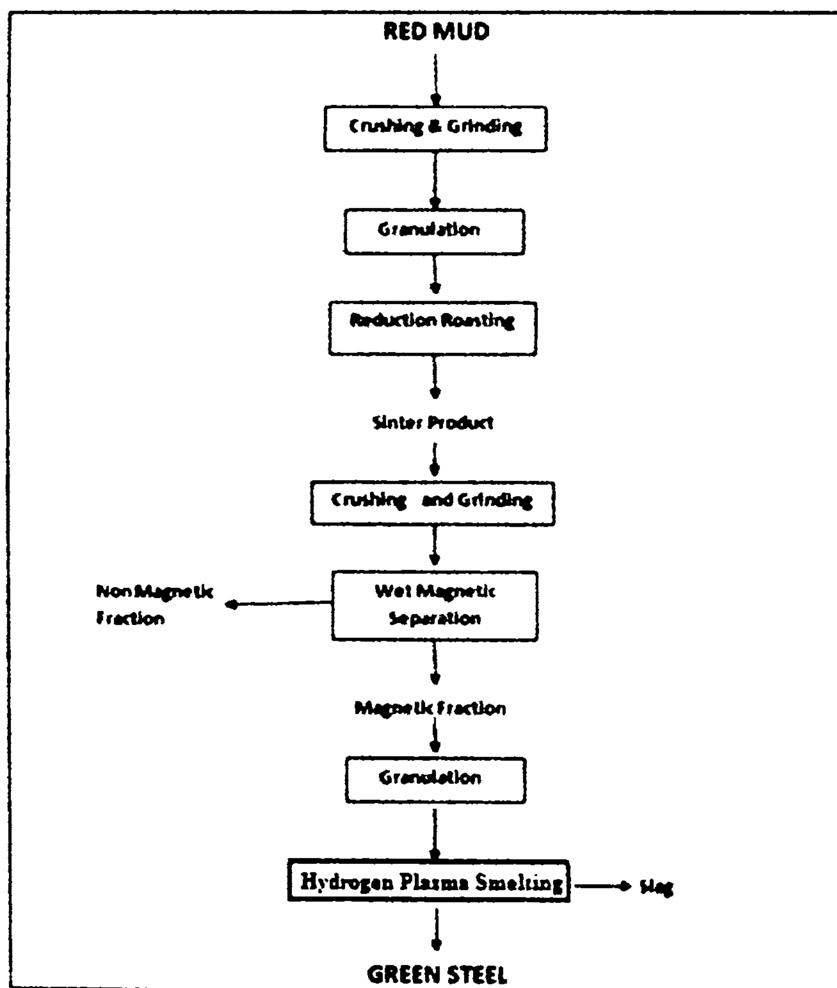


Figure 1. Process Flow Sheet for the Production of Green Steel from Red Mud

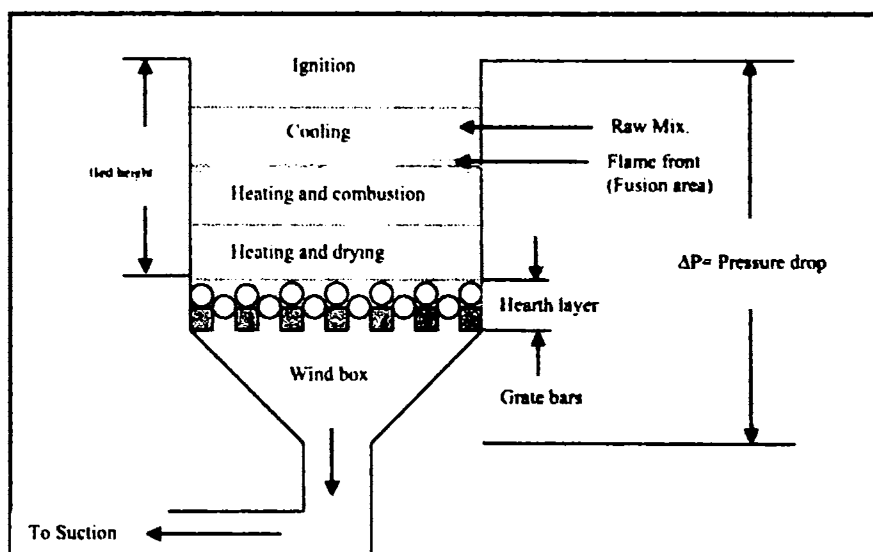


Figure 2. Schematic Diagram of Down Draft Sintering Unit

Table 2. Results of low intensity magnetic separation of red mud
(feed ground to 85% passing 75µm, intensity of magnetic field- 2000 gauss)

Details	Wt%	Fe%	Fe Recovery %
Roasted Feed	100	41.80	100
Magnetic Fraction	73.30	45.06	79.00
Non Magnetic Fraction	26.70	32.85	21.00

Hydrogen Plasma Smelting Process

In this process, the magnetic fraction of reduced red mud obtained through reduction roasting followed by magnetic separation technique was subjected to Hydrogen Plasma Smelting Process. The schematic diagram of the same has been shown in Figure 3. The plasma was generated with the help of plasma torch passing Argon gas through the centre of the torch. The melting of the reduced red mud occurs in the water cooled copper crucible of the reactor due to the high heat (2000°C) generated by plasma. Subsequently hydrogen gas was passed through the nozzle of the torch which acted as the reductant to reduce molten iron oxides present in red mud to metallic iron.

The Hydrogen Plasma Smelting Reactor consists of two distinct portions, one upper layer and the other lower layer. The lower layer consists of water cooled copper crucible which can be raised up and down during charging and discharging of samples. A typical experimental campaign was carried out with the pelletized reduced red mud sample (1-6mm size) in 200gm scale. Initially, about 50gm of the pelletized sample was kept in the water cooled copper crucible and the crucible was raised to the level of upper layer to close the reactor for operation. The arc was checked to ignite plasma into the reaction chamber with the help of argon gas passed through the centre of the plasma torch. The power supply was maintained at around 10-12 kW to facilitate the melting and reduction process simultaneously.After passing the argon gas at 10 lpm to the chamber for one minute, the reduced red mud sample present in the water cooled copper crucible was melted. Thereafter, hydrogen gas was passed through the nozzle of the plasma torch at a flow rate of 5 lpm along with argon gas for reduction of iron oxide present in red mud to metallic iron. Subsequently, the remaining feed materials were charged at the rate of 50gm/5minutes. The image of Hydrogen Plasma Smelting Reactor that was used for this innovative process has been shown in Figure 4

While carrying out the reduction process, the plasma torch was positioned at different angles (X x Y x Z directions) to ensure uniformity in the reduction process. To support better agitation of the molten metal with hydrogen, the electromagnetic stirrer was attached to the bottom of the water cooled copper crucible. After the reduction process was observed for a period of 25mins, the molten melt of metal and slag was brought down to room temperature. The metal and slag samples were separated by physical means and then the metal sample was analyzed for its chemical as well as mineralogical characterizations.

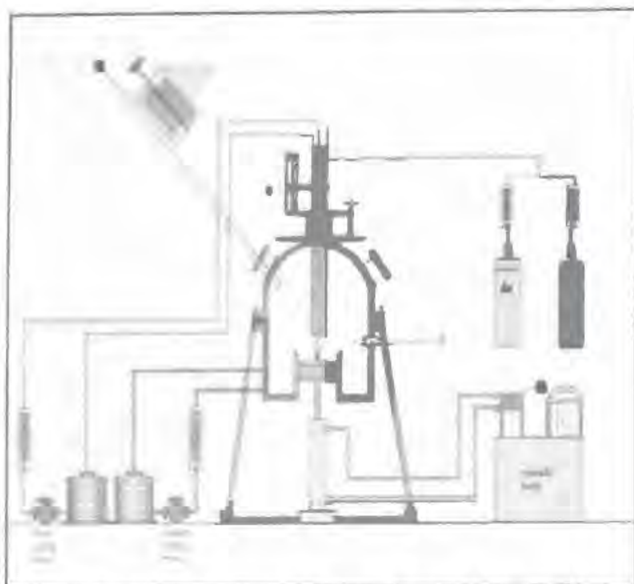

Figure 3. Schematic Diagram of Hydrogen Plasma Smelting Reactor


Figure 4. Hydrogen Plasma Smelting Reactor

Results and Discussions

Red mud containing good amount of Fe_2O_3 with some quantities of Al_2O_3 and other associated metal oxides, was subjected to beneficiation by reduction roasting followed by magnetic separation. The beneficiated red mud (the magnetic fraction) was then subjected to Hydrogen Plasma Smelting for the production of green steel. Al_2O_3 which is considered as a detrimental element for steel- making is eliminated by the process of reduction roasting and magnetic separations techniques. The magnetic fraction of reduced red mud containing rich in iron with low percentage of A_2O_3 was used as the feed material for the Hydrogen Plasma Smelting Process.

Conventional process of iron making uses carbon as a reductant, as a result of which carbonaceous gases are emitted causing environmental pollution. In the other hand, the present investigation utilizes one of the most novel and state- of- the- art technology for production of green steel using hydrogen gas as a reductant. In the process, molecular hydrogen is converted into atomic/ ionic forms of hydrogen which are more reactive and act as better reductant than carbon. No such carbonaceous gases are emitted in the process and only water vapor is released which can be recycled in the process after condensation.

Hydrogen gas also possesses unique characteristics of dissociating into atomic / ionic forms of hydrogen when it is subjected to thermal plasma state. The atomic ionic forms of hydrogen are three times and fifteen times more reactive than the molecular hydrogen respectively. Figure 5 describes the Ellingham-Richardson- Diagram which explains the relationship between free energy versus temperature depicting the manner in which molecular hydrogen behaves as the mild reductant for reduction of iron oxide in comparison to carbon [5-8] .The free energy of molecular hydrogen is -100 kcal. But when hydrogen gas is atomized/ ionized under thermal plasma, the free energy is shifted below -300 and -1500 kcal in all temperature ranges respectively and is capable of reducing all metal oxides present in the system more efficiently.

Reaction Mechanism at the Surface of the Molten Melt

In the molten state, iron oxide is present in the form of cationic and anionic for iron and oxygen respectively [9-11]. The atomic/ionic hydrogen comes in closed contact with the anionic oxygen thereby producing water vapor which is released from the system. This water vapor can be condensed and recycled into the process. The iron having higher specific gravity, settles down at the bottom of the melt and thereby forming a layer of the molten iron metal. The molten oxide layers in the anionic form, called slag, floats on the surface of the molten melt. This process continues till all the molten iron oxide melts reduced to metallic iron. After the reaction is over, the entire melt is cooled in the crucible of the reactor and the metal and slag layers are separated manually. The details of the reaction mechanism are adumbrated below at Figure 6.

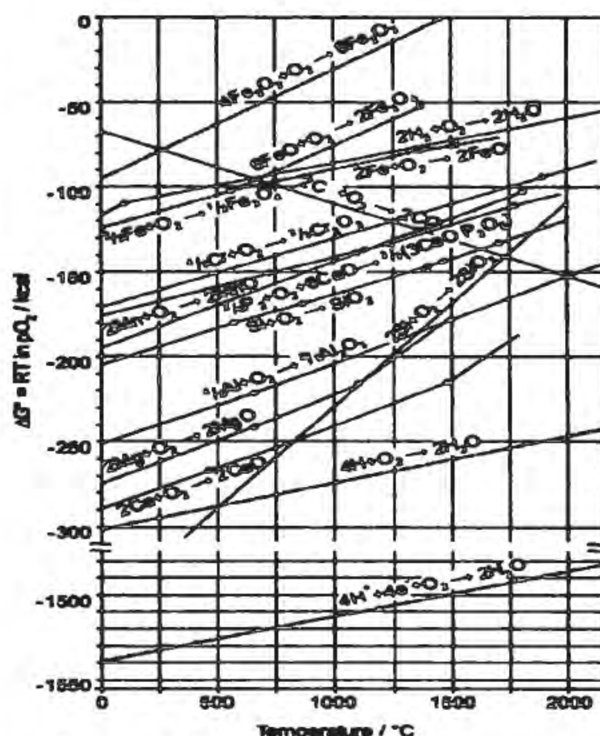


Figure 5. Ellingham-Richardson- Diagram

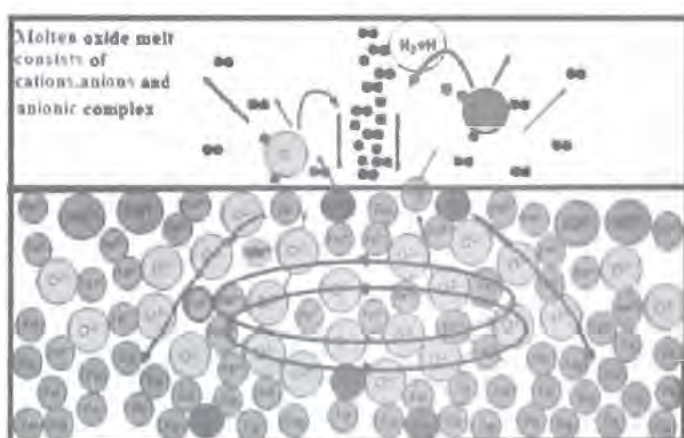


Figure 6. Reaction mechanism at the surface of the melt

Typical Experimental Findings

The beneficiated red mud sample (The magnetic fraction) was subjected to Hydrogen Plasma Smelting in 200gm scale as detailed under Hydrogen Plasma Smelting Process above. The casted sample in the crucible was collected and the metal sample was taken for chemical and mineralogical characterization. Photograph of the casted metal sample, called green steel, obtained after the experiment is shown in Figure 7. The chemical analysis of the metal sample is shown in Table 3. The XRD analysis of the final product is shown in the Figure 8 which shows the distinct peaks of Fe. The chemical and XRD analysis confirm the production of green steel from red mud.



Figure 7. The Photograph of green steel obtained from red mud using Hydrogen Plasma Smelting Reactor

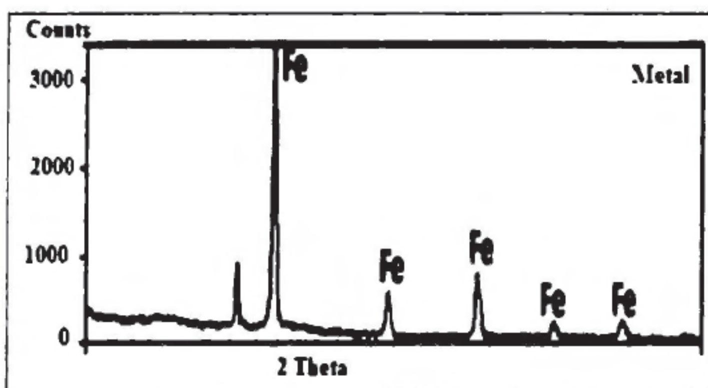


Figure 8. XRD analysis of green steel

Table 3. Chemical Analysis of Metal Product

Elements	Fe	P	S	C
%	97.03	0.02	0.007	0.02

Conclusion

From the above experimental evidences and observations, it can be concluded that red mud containing around 53.6% Fe_2O_3 and some appreciable quantities of Al_2O_3 and other associated metal oxides in minor quantities can very well be beneficiated through reduction roasting followed by wet magnetic separation to produce a feed material rich in iron and low in Al_2O_3 content.

The magnetic fraction of the reduced red mud can be used as a feed material for production of green steel employing the novel and state-of-the-art hydrogen plasma smelting technique. The process is eco-friendly and free from environmental pollution. Water, the only by-product produced in the process, can be condensed and recycled for use in the process.

The process has been successfully established in the laboratory scale and needs to be scaled up to pilot scale of operation before its commercial feasibility is established. CSIR-IMMT, Bhubaneswar, Odisha, India is in possession of laboratory scale technology for production of green steel from red mud or otherwise production of green steel from lean / high grade iron ores and the know-how is readily available for commercial exploitation.

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PRODUCTION OF NOVEL ZEOLITE OF TYPE Na-P FROM SODIUM ALUMINATE LIQUOR/SPENT LIQUOR/ALUMINA TRI-HYDRATE OF NALCO'S ALUMINA REFINERY, DAMANJODI,ORISSA,INDIA: A UNIQUE MATERIAL FOR DETERGENT FORMULATION

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Keywords: Bauxite, Sodium Aluminate Liquor, Alumina Tri-hydrate, Spent Liquor, Zeolite Na-P

Abstract

A Process for production of novel synthetic crystalline porous alumino silicate Zeolite Na-P consisting of the oxides of silicon and aluminium represented by the formula a $Na_2O:Al_2O_3$: b SiO_2,wherein a = 0.1-1.0 and b =2.2-5.0 has been developed from three different raw materials viz. Sodium Aluminate Liquor/ Spent Liquor/Alumina Tri-hydrate of NALCO's Alumina Refinery, Damanjodi, Orissa . Zeolite Na-P was produced by preparing a gel by mixing Sodium Silicate, Sodium Aluminate Liquor/Spent Liquor/Alumina Tri - hydrate, autoclaving the gel at 80-150 Degree Celsius for a period of 2 hrs to 4 days under static or stirred condition, quenching the resultant crystalline material in cold water, separating the catalyst formed, washing with water, drying the solid catalyst at a temperature of 80-120 Degree Celsius for a period of 3-12 hrs to obtain the product which can be used as a builder material for detergent formulation.

Introduction

In the past thirty-five years, Zeolites have stimulated a huge amount of academic and industrial research and impacted several adsorption, ion-exchange and catalytic processes. The commercial success of Zeolites was due primarily to their unique structure and composition controlled properties which permitted the improvement of known processes and the development of new ones.

The present work relates to a process for the preparation of novel crystalline aluminosilicate composite material using alumina source materials obtained from the alumina refinery of National Aluminium Company Ltd., Orissa, India. More particularly, this work relates to the preparation of crystalline micro porous aluminosilicate molecular sieve of Zeolite-P type structure exhibiting its suitability for several adsorption, ion-exchange and detergency processes of academic and industrial importance.

Compared to resins, Zeolites have found advantageous application as ion-exchangers in the last thirty years. In general, Zeolites are used where economic considerations or where a high thermal and/or radiation flux exclude the use of resins. Thus, Zeolites find application as water softeners in detergency where the relatively lower cost of Zeolites makes it an attractive option in such a 'throw-away' application or in the removal and storage of radio-nucleides where the considerable resistance of some Zeolites to radiation and thermal damage make them an obvious choice.

The term 'molecular sieve' was proposed in 1932 by J.W.McBain to describe the selective adsorption of molecules of relatively small size over molecules of larger size by Chabazite, a mineral Zeolite which has been purged free of adsorbed water. Zeolites are micro porous, crystalline, hydrated aluminosilicate molecular sieves. Structurally, they possess rigid three dimensional framework comprising of $[SiO_4]$ and $[AlO_4]$ tetrahedral linked through oxygen bridges and enclosing cavities and channels of molecular dimensions. Each $[AlO_4]$ tetrahedron imparts a negative charge on the framework of Zeolite. The framework negative charge is balanced by cations occupying extra-framework positions. A general formula for a Zeolite can be represented by its unit cell composition as:



$M_{x/n} [(AlO_2)_x (SiO_2)_y]. z H_2O$

Where M represents the exchangeable charge balancing cations usually from group I or II of the Periodic Table, with a valency 'n', x, y and z > 0. According to Lowenstein rule, the lower limit for y/x ratio tends to a value 1.0. Therefore, the relationship of aluminium to the charge balancing cations such as La/3, Ca/2, Na, K etc can be expressed as equal to unity. One type of cation may be exchanged either completely or partially with another cation following ion-exchanging techniques in a conventional manner. By means of such cation exchange, it has been possible to vary the properties of a given aluminosilicate by suitable selection of cation.

The reversible cation exchange is one of the important properties of crystalline alumino-silicate zeolites. The isomorphous replacement of Si^{4+} by Al^{3+} is responsible for the creation of a cation exchange site which is usually occupied by Na+. Zeolite-A, therefore, being the most aluminium – containing zeolite, offers maximum number of cation exchange sites. Therefore, until recently, Zeolite-A was used in the formulation of laundry- detergents of the non-phosphatic (free from STPP) type Zeolite extra-framework sodium cations, by replacing the cations like Mg^{+2}, Ca^{+2} etc. that impart hardness to water, thus renders soft water, easing out the washing action by the removal of dust particles etc.

The Hydrothermal Synthesis

Much of the success in the laboratory syntheses has come from the duplication of the conditions that produce natural zeolites. Zeolites are formed under hydrothermal conditions. The term hydrothermal is used in a broad sense and includes the crystallization of zeolites from aqueous system comprising of necessary ingredients. The essential process involved in the hydrothermal synthesis of most of the zeolites, is the conversion of amorphous reactive supersaturated aluminosilicate gels into crystalline ones, in the presence of aqueous solution of alkali and/or alkaline earth metal hydroxide at higher temperature (298-573K) The actual mechanism of zeolite crystallization is not well understood because of the complexity of the interactions occurring in the hydrothemal magma. The gross composition of reaction mixture contributes to a specific aspect of crystallization. However, there is a substantial interplay between the three variables viz.gross-composition, temperature and time during the course of crystallization.

In recent years, a number of patents have established the fact that Zeolite-P instead of Zeolite-A, is preferred in the formulation of laundry- detergents, perhaps on account of ease and higher rate of cation exchange including higher Magnesium ion-exchange capacity compared to zeolite of type-A. These zeolites will usually have calcium exchange capacity of at least 150mg CaO per gram of anhydrous aluminosilicate. Zeolite-P belongs to a family of small pore zeolites possessing low to intermediate Si/Al ratio (1.1 to 2.5).

The crystalline, porous aluminosilicate of type-P zeolite structure, prepared by the process developed are constituted of oxides of silicon and aluminium having well ordered porous structure consisting of channels of precisely defined and uniform dimensions. The zeolite type Na-P prepared by the process developed has a chemical composition , in terms of oxide mole ratios on dry basis as follows:
$0.01\text{-}1.0\ Na_2O \cdot Al_2O_3\ 2.2\text{-}5.0\ SiO_2$

Accordingly, the process developed for the preparation of novel synthetic crystalline zeolite of type Na-P consisting of the oxides of silicon and aluminium by the hydrothermal crystallization process having in the mole ratios of oxides in the anhydrous state represented by the formula:


$a\ Na_2O \cdot Al_2O_3 \cdot b\ SiO_2$

wherein a =0.1 - 1.0 and b=2.2 - 5.0 and characterized by X-Ray Powder Diffraction Data which comprises preparing a gel by mixing a source of silicon, aluminium and sodium, autoclaving the resultant gel at a temperature in the range of 80-150° C for a period ranging between 2hrs to 4 days under static and/or stirred condition, quenching the resultant crystalline material in cold water, separating the catalyst formed by conventional methods, washing with deionised water thoroughly up to wash water pH is in the range of 9.0 to 11.0, drying the solid catalyst at a temperature in the range of 80-120°C for a period ranging from 3-12 hrs. to obtain the product.

Table -1 Representative Physical Properties Data for Zeolite-P

Chemical Composition:	
Typical Oxide Formula	: $Na_2O.\ Al_2O_3\ \ 2\text{-}5\ SiO_2$ 5H2O
Typical Unit Cell Content	$Na6\ [(AlO_2)_6\ (SiO_2)_{10}]$ .15 H2O
Variations	Si/Al = 1.1 to 2.5
Crystallographic Data	
Summitry	: Near Cubic
Space Group	: I4/amd
Density	: 2.01g/cc
Unit Cell Volume	: 1015A^3
Unit Cell Constant	: a = 10.05 A^0
Structural Properties	:
Framework	: Same as gismondine
SBU: S4R	
Void Volume	: 0.41cc/cc
Framework Density	: 1.57 g/cc

Analysis of NALCO Origin Raw Materials

The NALCO origin raw materials viz. Alumina Tri-hydrate, Sodium Aluminate Liquor and Spent Liquors were analyzed and the chemical analyses are presented in Table-2 below.

Table-2 .Chemical Analysis of NALCO Origin Raw Materials

Wt. % ⇨ / Material ⇩	LOI	Al_2O_3	Na_2O	K_2O	Fe_2O_3
Alumina Trihydrate Powder	33.84	65.35	0.66	0.04	0.11
Sodium Aluminate Liquor					
Sample-I	78.68	10.11	11.12	0.086	ND
Sample-II	77.70	9.83	11.70	0.077	ND
Sample-III	79.84	8.19	11.88	0.089	ND
Sample-IV	77.41	10.00	11.87	0.089	ND
Spent Liquor					
Sample-I	79.38	6.12	14.50	ND	ND
Sample-II	78.57	6.37	15.06	ND	ND
Sample-III	78.58	6.29	15.13	ND	ND
Sample-IV	78.61	5.94	15.45	ND	ND

ND= Not Detectable

The nature of the raw materials and their treatment prior to the formulation plays an important role in the crystallization process. Attention was focused in the formation of zeolite of type Pc by reproducible, economical

processes and by utilizing mildest possible conditions. The concentration of reacting components in the initial gel formation is one of the major factors in determining the species produced. Accordingly, attempts were made to develop a process for crystallization of zeolite-P using NALCO based raw materials.

Preparation of Zeolite –P using NALCO origin Sodium Aluminate Liquor

(A)Laboratory Scale Studies:

The analysis of Sodium Aluminate Liquor showed that the Na_2O content was 11.5±0.4 whereas % Al_2O_3 was ranging from 8.19 to 10.60. The variation in the alumina content may be due to settling down of alumina during transport of sample and ageing. Since Na_2O content is high, the gel composition from which Zeolite-P was crystallized using synthetic Sodium Aluminate viz.$2.58Na_2O:Al_2O_3:3.8SiO_2:94H_2O$ was found to be unsuitable for preparation of Zeolite-P using NALCO origin Sodium Aluminate Liquor.Na_2O/SiO_2,H_2O/Na_2O ratios and nature of the raw material were found to be the influencing synthesis parameters, different compositions were examined on the basis of the earlier results. Each composition was again subjected to different hydrothermal conditions for crystallization. However, after optimizing gel composition, a part of the investigation is summarized in Table-3 indicating the complexity in optimizing the synthesis conditions using NALCO origin Sodium Aluminate Liquor as a source of aluminium. The gel composition was chosen as $4.39Na_2O:Al_2O_3:3.56SiO_2:225H_2O$.NALCO origin Sodium Aluminate Liquor from Sample-I was used as a source of aluminium. For silica source, Sodium Silicate (28% SiO_2, 8.5% Na_2O) was used for the gel preparation. In a gel preparation, 15ml water was added to 14.98 g of Sodium Silicate and stirred for 10 minutes. To this was added a solution of 20.18 g Sodium Aluminate diluted with 20ml of water with constant stirring for 10 min. 2.48g NaOH in 21ml of water was added to the above resultant mixture with constant stirring for 15 minutes. The resultant gel was further stirred for about 30 minutes. The homogeneous gel so formed was then transferred to the stainless steel autoclave. For each experiment, starting gel was prepared freshly with the same composition and then subjected to the desired hydrothermal treatment as tabulated in Table-3.After the autoclave attained the desired temperature, the time was recorded as the zeroth hour. The heat-up time varied for the different temperatures. The heat-up time was estimated as the time needed to attain the set temperature of the oven in the reactor after keeping it in the oven. The autoclaves were quenched to room temperature and solid product was separated by suction filtration. Sufficient washing of the wet cake with distilled water was ensured by checking pH of the filtrate and colour of the solid product. The product was dried at 120°C for 4 hrs.

Physico-chemical Characterization: The pure, crystalline Na-P type zeolite obtained from Batch No. 11 of Table-3 was characterized by powder X-ray diffraction, Infrared Spectroscopy, Scanning Electron Microscopy, Chemical Analysis by Atomic Absorption Spectroscopy and X-Ray Fluorescence techniques, Calcium Exchange Capacity and Whiteness Index.

Table-3 Crystallization of Zeolite of type-P using NALCO Sodium Aluminate Liquor as a Source of Aluminium.

Batch No.	Aging Temp.(°C)	Period (hrs.)	Crystallization Temp.(°C)	Period (hrs.)
1	-	-	85	9
2			100	24
3			110	12
4	-	-	120	6
5.	-	-	120	8
6	-	-	120	16
7	-	-	120	24
8	100	12	110	2
9	100	12	110	4
10	100	12	110	6
11	100	12	110	8
12	100	12	110	10
13	100	12	110	12
14	100	16	110	16
15	100	16	110	25

Chemical Analysis: $(Si/Al)_{Chem. Anal.}$ = 1.52, $(Si/Al)_{XRF}$ =1.49
Calcium Exchange Capacity: 169.4mgCaO per 1 gm of anhydrous Zeolite-P Whiteness Index: 95(with respect to) $BaSO_4$).

(B) Scaling Up:
Based on the above results, an attempt was also made for scaling up by using autoclave of 20 l capacity equipped with open turbine type agitator. The oxide mole composition in the initial gel mixture used in the scaling-up runs was $4.24Na_2O:Al_2O_3:3.56\ SiO_2:\ 225\ H_2O$. In the first scaled-up batch, the quantities weighed and mixing sequence followed were as follows.

2 l of distilled water was added to 1.526 Kg of Sodium Silicate and stirred for 10 minutes. To this was added a solution of 2.018Kg of Sodium Aluminate Liquor of NALCO origin diluted with 1 l of distilled water with constant stirring for 15 minutes. 0.222Kg of NaOH pellets were dissolved in 1.5 l of distilled water and it was added to the above resultant solution with constant stirring for 15 minutes. The formed gel was further stirred for about 2 hrs and then this homogeneous gel was transferred to an autoclave of 20 l capacity. The temperature was raised using the following programme

a) Room Temp. to 50° C: time taken - 1hr 15min.
b) 50°C -75°C : time taken- 30min.
c) 75° C- 100°C : time taken -30min and allowed to age for 12hrs.
d) 100°C – 110°C . time taken – 45 min. and allowed to crystallize for 8 hrs.

In order to check the progressive crystallization of desired phase, samples were removed after different length of crystallization period viz. 5hr, 6hr 30 min and 8 hr and they were examined by XRD after filtration, washing and drying. After confirming the purity and crystallinity to

maximum extent, the product was drained out after cooling the autoclave to room temperature. Product was separated by suction filtration and washed by distilled water till the effluent showed pH in the range of 9.5 - 10.5. Solid was dried at 110°C for at least 4 hrs. The dried product was characterized by XRD, XRF, SEM and for Whiteness Index and Calcium Exchange Capacity. These results are shown in Table-4 along with the characteristics of the products obtained from the next scaled-up processes from batch –II to batch-IV. The quantities of raw materials used for scaling up the process for different batches are summarized in Table- 5.

Table-4.Characteristics of the Products Zeolite-P obtained from the Scaled-up batches

Analysis	Batch-I	Batch-II	Batch-III	Batch-IV
Chemical Analysis ($Si/Al_{chem\,anal}$) (Si/Al_{XRD})	1.48 1.47	1.52 1.49	1.50 1.52	1.49 1.47
Calcium Exchange Capacity mg of CaO/g anhyd.)	170	170	163	171
Whiteness Index (w.r.to $BaSO_4$)	96	95	95	96

Table-5.Quantities of Raw Materials used for Scaling-up the Process

Batch No.	Sodium Silicate (kgs)	Sodium Aluminate Liquor (kgs)	NaOH (kgs)	Total H_2O (Lit.)
1	1.526	2.018	0.222	5.5
2	2.289	3.027	0.333	8.25
3	3.052	4.036	0.444	11.0
4	3.052	4.036	0.444	11.0

Preparation of Zeolite of type P using NALCO origin Alumina Tri-hydrate (ATH) Powder

(A) Laboratory Scale Studies:

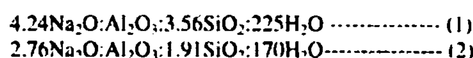
Experiments were conducted without any prior treatment for the dissolution of ATH in order to seek the possibility of reducing this additional step during the synthesis and thereby energy consumption.

Table-6.Details of Synthesis runs using NALCO based ATH

Batch No.	Oxide Mole Composition	Crystallization Time	Period	XRD
1	$2.4Na_2O:Al_2O_3:3.87SiO_2:145H_2O$	110°C	8hrs.	HS
2	$2.4Na_2O:Al_2O_3:3.87SiO_2:145H_2O$	120°C	8hrs.	Unknown phase
3	$2.4Na_2O:Al_2O_3:3.87SiO_2:145H_2O$	105°C	8hrs.	Pc+Unknown phase
4	$2.4Na_2O:Al_2O_3:3.87SiO_2:145H_2O$	85°C	8hrs.	Unknown phase
5	$2.4Na_2O:Al_2O_3:3.87SiO_2:145H_2O$	1100C	12hrs	Unknown phase
6	$3.9Na_2O:Al_2O_3:2.42SiO_2:154H_2O$	110°C 120°C	12hrs 24hrs	HS
7	$4.22Na_2O:Al_2O_3:3.87SiO_2:145H_2O$	110°C	8hrs.	Pc+ analcime
8	$4.22Na_2O:Al_2O_3:3.87SiO_2:145H_2O$	120°C	12hrs.	HS
9	$5.17Na_2O:Al_2O_3:3.87SiO2:145H2O$	120°C	12hrs	Pc+HS
10	$2.76Na_2O:Al_2O_3:1.91SiO_2:170H_2O$	120°C	8hrs.	HS
11	$3.75Na_2O:Al_2O_3:3.5SiO_2:160H_2O$	1200C	40hrs	Mix phase
12	$4.24Na_2O:Al_2O_3:3.56SiO_2:225H_2O$	100°C 110°C	12hrs 6hrs	Mix phase
13	$8Na_2O:Al_2O_3:6.7SiO_2:344H_2O$	100°C 110°C	12hrs 6hrs	Pc+ analcime
14	$8Na_2O:Al_2O_3:6.7SiO_2:344H_2O$	120°C	17hrs	Pc+ analcime

In the typical gel preparation using composition-1 from Table- 6, 16.28g of sodium silicate was diluted with 10ml of distilled water and kept under mechanical stirring.3.12g alumina tri-hydrate powder of NALCO origin(65.35% Al_2O_3)was mixed with 2.1g of NaOH (96% Ranbaxy) &30ml of distilled water. This mixture was then added in to Na_2SiO_3 solution slowly. The resultant mixture was then stirred further for 30min. and then transferred to a Teflon lined stainless steel lined autoclave. This autoclave was then subjected to the hydrothermal treatment in an air oven and temperature was raised stepwise to 110°C. It was allowed to crystallize for a period of 8hrs.After 8hrs., autoclave was quenched, product was filtered, washed thoroughly to remove excess Na_2O and then dried in an oven at 110°C for 6 hrs. XRD profile of this product confirms the presence of HS phase. Similarly, without dissolution of ATH, different compositions at different reaction parameters yielded other than pure Na-Pc phase. Some unidentified phases, HS, analcime, etc. have been formed predominantly in the pure form or in the major contribution as a result of using as- supplied form of ATH from the alumina refinery plant of NALCO. Therefore, it was decided to conduct the experiments with prior treatment of dissolution of as- supplied form of ATH.

Further attempts were made to optimize synthesis conditions including the oxide mole compositions which will yield pure crystalline Na-P with reasonably good reproducibility. Following compositions gave the satisfactory results.



$4.24Na_2O:Al_2O_3:3.56SiO_2:225H_2O$ --------------- (1)
$2.76Na_2O:Al_2O_3:1.91SiO_2:170H_2O$--------------- (2)

Scaling -up:

For the dissolution of ATH using composition (1), 352 g of ATH was mixed with a solution of 578g of NaOH dissolved in 3 l of distilled water. This solution of ATH was then heated in a S.S.autoclave of 20 l capacity followed by increasing the temperature up to 120°C and examined the extent of dissolution at 6,8,12,16,18,24, 36 & 48hrs. Instead of increasing temperature for the complete dissolution increase in the strength of alkali solution was preferred by decreasing the quantity of water by 50% .Same set of experiments were carried out at 120°C for different length of period. After 16 hrs. a clear solution of

ATH was obtained indicating complete dissolution. This solution was then discharged and water loss was adjusted by adding required amount of distilled water.1.686Kg sodium silicate was diluted with 5.3 l of distilled water with constant stirring. Clear solution of ATH was then added slowly under vigorous stirring to the diluted sodium silicate solution. The gel mixture formed was further stirred for 2hrs. until the gel becomes homogenous. It was then transferred to an autoclave of 20 l capacity with the help of addl. one liter of distilled water. The autoclave was then heated to 100°C by stepwise increment viz. (a) from room temp. to 50°C. (b) from 50°C to 100°C and hold for 12hrs. Then the temperature was further increased from100°C to 110°C.After 6 hrs cooling was started under normal condition and then the product was discharged along with the mother liquor. Product was separated by vacuum filtration followed by washing till effluent showed pH in between 9-11.Product was dried in an air oven at 120°C for 4 hrs. XRD profile showed pure and well crystalline Na-Pc phase. Using composition(2) ,another scale up experiment was carried out in the similar way as above and XRD profile showed pure and well crystalline Na-Pc phase. Comparative details of above scaled –up representative batches are summarized in Table-7.

Table-7.Comparative studies of scaled -up batches using different compositions

Batch Compo-sition	Weight(Kg) raw material taken				Crystallization Temp./Time	Yield (g)	Product Si/Al XRF
	Sod Silicate	ATH	NaOH	H2O			
(1)	1.686	0.352	0.578	7.800	100°C/ 12h 110°C/ 6h	759	1.39
(2)	1.206	0.473	0.530	8.139	120°C/8h	501	1.51

Table-8.The physico –chemical characterization of the products

Analysis	Composition(1)	Composition(2)
Chemical Analysis $(Si/Al)_{chemical\ analysis}$ $(Si/Al)_{XRF}$	 1.38 1.39	 1.44 1.51
Calcium Exchange Capacity Mg of Cao/g(anhyd.)	163	160
% Whiteness Index (w.r.to $BaSO_4$)	94	94

Preparation of Zeolite-P using NALCO origin Spent Liquor

(A)Laboratory Scale Studies.

For undertaking laboratory scale study, following two modified compositions were tried for hydrothermal crystallization for preparation of Zeolite-P using NALCO origin Spent Liquor.

(a) $4.98Na_2O:Al_2O_3:1.91SiO_2:170H_2O$
(b) $4.98Na_2O.Al_2O_3:3.56SiO_2:225H_2O$

Studies were conducted for increasing the SiO_2/Al_2O_3 mole ratio in the gel mixture by reducing the alumina content. However, with the change in quantity of alumina, the change in Na_2O content was made in such a way that they fall in proper range H_2O/Na_2O and Na_2O/SiO_2 mole ratios favorable to yield Na-P phase. Experiments with reducing alumina moles systematically from1.0 mole to 0.75 moles, 0.7 moles, 0.6 moles and to 0.5 moles were conducted. Table-9 summarizes the runs carried out at different temperature and period.

Table-9.Laboratory scale runs using spent liquor

Batch No.	Molar SiO_2/Al_2O_3 in gel mixture	Crystallization Temp./Period	Phase Identification (XRD)
1	3.56	120°C/8hrs.	X +A+HS
2	4.75	120°C/8hrs.	X+Na-Pc traces
3	5.33	100°C/12hrs. 110°C/6hrs.	X+Na-Pc traces
4	5.33	120°C/8hrs.	X+Na-Pc traces
5.	7.11	120°C/8hrs.	Na-Pc
6	7.11	120°C/8hrs.	Na-Pc
7	7.11	100°C/12hrs. 110°/6hrs.	Na-Pc

It is evident from the Table-9 that pure Na-Pc was crystallized with only SiO_2/Al_2O_3 ratio equal to 7.11. The composition 6.66 $Na_2O:Al_2O_3:7.11SiO_2:448H_2O$ was further examined with reducing water content in order to reduce the batch volume. Unfortunately, H_2O/Na_2O molar ratio below 67.27 failed to form Zeolite-P phase in present studies keeping SiO_2/Al_2O_3=7.11 andNa_2O/SiO_2 ratio=0.936. In a typical gel preparation, 22.44 g of sodium silicate was diluted with 45 ml of distilled water and kept under stirring for 15 mins. 24.03 g of spent liquor diluted with 43ml of H_2O was added slowly in to the above solution for 20 min. under vigorous stirring. The gel mixture formed was then further stirred for 30 min. for homogeneity. This gel mixture was then transferred to Teflon lined S.S. autoclave which was then subjected to an oven at 120°C for 8hrs.The temperature 120°C was achieved stepwise in order to avoid shooting up of the desired temperature. Kinetics of crystallization using this composition was studied by preparing fresh gel for each batch and quenched after 2, 4,6,8,10,12 & 16 hrs. After quenching autoclave, product was filtered and washed with distilled water. The wet cake of the product was then dried in an oven at 120°C for 6 hrs. XRD profile of the product obtained after 8 hrs showed the most pure and fully

crystalline Na-Pc phase. Further, the effect of ageing was also examined for the final Si/Al ratio in the product and morphology. As there was only marginal difference in the both, the batch with less crystallization time was preferred for the scaling up studies.

(B) Scaling up:

For scaling up, autoclaves of 20 l, 50 l and 500 l capacity equipped with open turbine type agitator were used for batches A, B and C respectively and summarized in Table 10 and 11.

Table-10. Step-wise scaling up using NALCO Spent Liquor

Batch No.	Weights(Kg) of raw materials taken			Yield(g)	Crystallinity (%)	Si/Al (XRD)
	Sodium silicate	Spent Liq.	Water			
A	2.244	2.403	8.8	702	93	1.69
B	6.760	7.209	26.4	2020	95	1.70
C	58.63	63.15	227.0	18,440	97	1.69

Table-11. The physico-chemical characterization of the final products obtained from the above three scaled-up batches.

Analysis	Batch-A	Batch-B	Batch-C
Chemical Analysis $(Si/Al)_{chem.\ analysis}$ $(Si/Al)_{XRD}$	 1.69 1.68	 1.71 1.69	 1.68 1.70
Calcium Exchange Capacity Mg of CaO/g(anhyd.)	162	160	161
% Whiteness Index (w.r.to $BaSO_4$)	96	96	96

Conclusion

Results of the above laboratory and scale-up studies indicated that that Zeolite-P can be produced from NALCO origin raw materials viz. Sodium Aluminate Liquor/Alumina Tri-hydrate/Spent Liquor which can be used as a builder material in detergent formulation having better efficiency than detergent grade Zeolite-A.

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INVESTIGATION OF ALUMINA DISCHARGE INTO THE RED MUD POND AT NALCO'S ALUMINA REFINERY, DAMANJODI, ORISSA, INDIA

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Keywords: Bauxite, Alumina Discharge, Red Mud

Abstract

Around 14% of alumina gets discharged into the red mud pond from NALCO's alumina refinery. The minerals hosting alumina in red mud have been investigated using Optical microscope, Scanning Electron Microscope (SEM), Electron Probe Micro Analyzer (EPMA) and XRD. The minerals in red mud sample, as identified through integrated techniques, are: gibbsite, boehmite, goethite, silimanite, muscovite, garnet and kaolinite besides minor hematite, sodalite and rutile. The average particle size of red mud is ~8μm except isolated grains of gibbsite, goethite and garnet which are greater than 20μm in size. The gibbsite invariably contains up to 60 mole % of boehmite. The nodular goethite contains over 30-mol % of 'Al' in its lattice and termed as alumo-goethite. Around 34% of the Al_2O_3 is present in muscovite/silimanite/garnet. Studies reveal that most of the minerals in red mud have either alumina in their lattices or are undigested aluminium silicates that do not get dissolved during alumina refining, thus a considerable amount of alumina gets discharged through these phases into the red mud.

Introduction

Around 2 tons of caustic insoluble waste residue known as 'Red Mud' is generated from NALCO aluminium refinery at Damanjodi, Koraput district, Orissa for every ton of alumina produced. Aluminium metal is extracted from aluminium oxide phases that constitute only 38 to 60% of the original bauxite ore. The rest is made up of Fe_2O_3, SiO_2, TiO_2 and many other oxide phases. After dissolution of the bauxite in caustic soda, these impurities remain in suspended form which is separated out after being washed and then pumped in a slurry to the nearby pond called the Red Mud Pond. India accounts for about 2 Million tons of red mud per year of which is more than half the quantity is generated at the NALCO refinery. This industrial waste material poses tremendous environmental and disposal problems. Reduction in the quantity of red mud is possible only through their utilization in one form or another. However, the inherent complexity of red mud poses problem in its bulk utilization. Prior to going for bulk utilization of red mud rejects from the NALCO refinery, it needs in-depth characterization. Rao et al [1] have reported the characteristics of undigested sand rejects from the NALCO refinery. Only limited attempts have been made on the characterization of red mud sludge from this refinery [2-5].

Fine particles of red mud can be characterized only through selected instrumental techniques. The present paper describes the characteristics of NALCO red mud through scanning electron microscopy and electron probe micro-analysis with a view to finding out the reason for alumina discharge into the red mud pond during the alumina refinery process.

Materials and Methods

For this study, representative red mud sludge was collected from the red mud pond of NALCO alumina refinery. After washing and oven drying, the sample was sprinkled on double sided adhesive conducting tape, placed over the sample holder and studied under SEM (JSM 35CF) equipped with WDS & EDS systems. Compositional x-ray analysis was undertaken for selected minerals.

Chemical compositions of various phases were determined by an ARL-SEMQ-II electron microprobe in the Geochemisches Institute, Universitat Gottingen, Germany, which is equipped with six spectrometer and four different analyzing crystals. The operating conditions were 15 kV accelerating voltage and 15 nA sample current. ZAF - corrected representative mineral analyses are presented in Table -1.

Morphology and Mineralogy

In the red mud sample, about 35% by weight of solids contain less than 5-micron particles and the average size is found to be around 8 micron. However, a few independent grains > 20μm size (about 10%) are also present. Due to the very fine size, some of the particles appear coagulated.

Broad mineral species present in the red mud sample were identified through XRD (Philips). As can be seen from XRD pattern illustrated in Fig.1, the red mud sample contains gibbsite, boehmite and sodalite as alumina bearing; goethite and hematite as iron bearing and rutile as titanium bearing phases. Goethite, hematite, rutile, kaolinite and mica were recognized under optical microscope.

Some of these alumina bearing minerals were subsequently analyzed under electron micro-probe. Gibbsite and goethite are observed to be dominating phases in the red mud sample. Gibbsites occur in pseudo hexagonal or prismatic habit. Goethite is either flaky or nodular, the later showing bunches of rotund units. Presence of fine grains of rutile, ilmenite, and zircon are recorded in subordinate amount. In addition, flakes of kaolinite, mica, needles of sillimanite (as litho relics) and sub-rounded grains of garnet are also noticed.

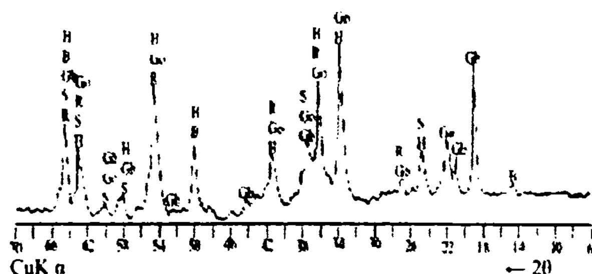


Fig. 1: XRD pattern of Red-mud
[H: Hematite, Go: Goethite, S: Sodalite, Gb: Gibbsite, R: Rutile, B: Boehmite]

Mineral Chemistry

A few selected mineral grains viz. gibbsite, goethite and kaolinite, muscovite (precursor minerals not completely replaced by alumina) from red mud were exposed under electron probe microanalyser (EPMA) to know the extent of alumina in them (Table 1-3). Most of the idiomorphic crystals appearing as gibbsite under scanning electron microscope are found to have undergone dehydroxylation containing up to 60 mole % of boehmite in solid solution (Table 1).

The nodular type of goethite contains alumina in its lattice (Fig. 2). Such alumina-rich goethite is termed as alumo-goethite by Jonas and Solymar [6] Since goethite grains in the NALCO red mud are found to contain 30 mol % of alumina, it may be termed as alumo-goethite. 30 to 39% of Al_2O_3 are recorded in litho relict minerals like kaolinite and muscovite flakes (Table 2 & 3). Compositional maps of kaolinite, silimanite and garnet grains in red mud (Figs. 3-5) indicate that these minerals are not converted to gibbsite.

Table 1. Electron Probe Microanalysis Results of Selected Alumina-rich Grains from Red Mud

Compound,%	1	2	3	4
Al_2O_3	78.30	71.82	69.94	65.60
FeO	0.26	0.00	0.00	0.00
	0.04	0.00		
SiO_2	0.00	0.00	0.36	0.10
MgO	0.00	0.00	0.07	0.00
MnO	0.49	0.22	0.00	0.00
CaO	0.04	0.00	0.02	0.00
K_2O	0.00	0.00	0.00	0.00
Na_2O	0.00	0.00	0.00	0.04
TiO_2	–	–	0.00	0.01
AlOOH	69.44	49.90	35.65	2.35
$Al(OH)_3$	29.63	49.87	73.69	97.31
FeOOH	0.32	0.00	0.00	0.00
Other Oxides	0.93	0.23	0.66	0.34

Note: Column 1: Boehmite dominating; 2: Mixed boehmite-gibbsite; 3: Mixed gibbsite-boehmite; 4: Gibbsite dominating

Table 2. Electron Probe Microanalysis results of Kaolinite and Goethite

Compounds,%	1	2	3	4
SiO_2	45.859	43.834	0.795	0.70
Al_2O_3	39.228	38.009	0.957	18.48
FeO	0.145	0.049	85.012	52.63
MgO	0.076	0.058	–	--
MnO	0.000	0.018	--	--
TiO2	--	--	–	6.12
CaO	0.054	0.134	--	0.42
K_2O	0.025	0.033	0.013	--
Na_2O	0.203	0.064	--	--
Cr_2O_3	0.076	0.127	--	–
BaO	0.000	0.017	–	--
NiO	0.009	0.000	–	--
CaO	0.236	0.211	--	–
H_2O_{Calc}	--	--	12.20	21.44
	Based on 08 cation		Based on 1 cation	
SI	3.95	4.05	0.01	0.01
Total 1	3.95	4.05		
Al	3.98	3.90	0.015	0.30
Fe	0.01	--	0.974	0.62
Mg	0.01	0.01	–	--
Mn	–	--	--	--
Co	0.02	0.01	–	--
Total 2	4.02	3.93		
Na	--	0.01	--	--
K	0.03	0.01	–	--
Ca	--	–	–	0.01
Ti				0.06
Total 3	0.03	0.02	--	--

Note: Column 1 & 2: Kaolinite; 3: Goethite; 4: Alumo-goethite

Reasons for Discharge of Alumina Phases into Red Mud

After the soluble aluminium containing oxides and hydroxides are recovered in the Bayer process, other metal oxides present in the bauxite are disposed as a red mud material. However, discharge of alumina rich phases into the red mud pond, resulting loss in alumina recovery, is of great concern. Discharge of alumina to an appreciable extent (Av. Al_2O_3: 14%) into the red mud pond may be attributed to gibbsite containing boehmite in solid solution, alumo-goethite having 30 mol% of alumina in its lattice, needles of silimanite, specks of mica and garnet (litho-relict minerals) and minute kaolinite platelets recorded in the red mud. All such mineral phases do not get dissolved during the industrial treatment of bauxite with caustic soda and ultimately get into the red mud pond.

However, an in-depth study is necessary to improve the efficiency of digestion of all these phases during the Bayer process, so as to recover the alumina value from at least some of them. Volkov et al [7] reported that by increasing the amount of lime at 240° C, it is possible to completely break down alumino-goethite.



Fig. 2. Compositional X-Ray Map of Fe & Al in Alumo-goethite found in Red Mud. Image Map of Iron, Alumina confirms the Presence of significant Alumina in the Goethite Lattice

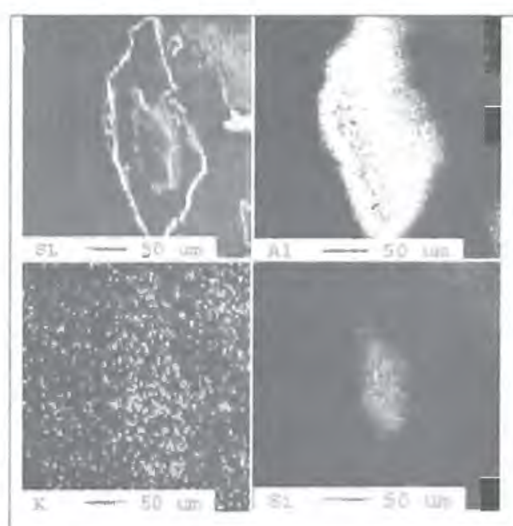


Fig. 3. Compositional X-Ray Map of K, Al & Si in a Litho Relict Observed in Red Mud. The Silica Rich Phase Still Occupies the Core Region and hence escaped leaching



Fig.4. Compositional Map of Si & Al in Sillimanite Grain Present in Red Mud. Presence of Silica and Alumina indicates its poor leaching during Bauxitisation Process

Table 3. Electron Probe Micro-analysis Results of Muscovite

	01	02	03	04
SiO_2	46.526	46.566	44.529	44.407
Al_2O_3	34.074	34.566	33.120	30.493
FeO	1.651	1.725	1.711	1.177
MgO	0.498	0.455	0.482	0.375
MnO	0.000	0.102	0.045	0.00
CaO	0.000	0.012	0.015	0.00
K_2O	11.697	10.270	10.734	10.304
Na_2O	0.400	0.441	0.455	0.426
TiO_2	0.214	0.350	0.355	0.248
BaO	0.000	0.00	0.00	0.076
Based on 14 cations				
Si	6.22	6.28	6.20	6.47
Al	1.78	1.72	1.80	1.53
Total 1	8.00	8.00	8.00	8.00
Al	3.60	3.78	3.63	3.72
Fe	0.19	0.19	0.20	0.14
Mg	0.10	0.09	0.10	0.08
Mn	--	0.01	0.01	--
Ti	0.02	0.03	0.04	0.03
Cr	--	--	--	--
Total 2	3.91	4.10	3.98	3.97
Na	0.10	0.12	0.12	0.12
K	1.99	1.78	1.90	1.91
Total 3	2.09	1.90	2.02	2.03

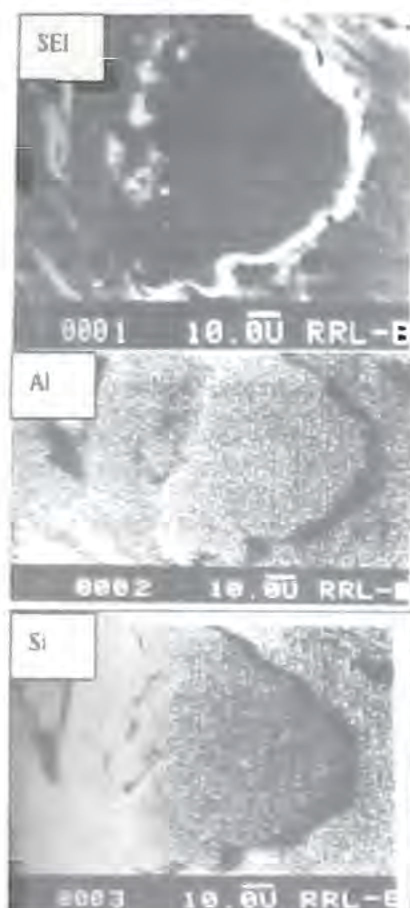


Fig. 5. Compositional Map of Si & Al in Relict Garnet Present in the in Red Mud

Conclusions

The red mud sludge from the NALCO alumina refinery at Damanjodi, Orissa, has been characterized using SEM-WDS and EPMA techniques. These are very fine grained muds, the average size being 8 micron. Different alumina containing phases such as alumo-goethite, sillimanite, kaolinite, mica and garnet were identified from their micro-morphology and in-situ chemical analysis, which contribute to the loss of alumina into the red mud. The presence of dehydroxylated grains of gibbsite probably indicates the higher temperature (than that for pure gibbsite) required for their dissolution.

The mineral chemistry of some of the constituent phases in red mud reveals the presence of lattice bound alumina which escapes the digestion stage in the Bayer's process, resulting in loss of alumina during the refining process at NALCO.

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NON-FERROUS METALS
Uses & Applications



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In metallurgy, a non-ferrous metal is a metal, including alloys that does not contain iron (ferrite) in appreciable amounts. Generally, more expensive than ferrous metals, non-ferrous metals are used because of desirable properties such as low weight (e.g. Aluminium), higher conductivity (e.g. Copper), non-magnetic property or resistant to corrosion (e.g. Zinc). Some non-ferrous materials are also used in the iron and steel industries. For example, bauxite is used as flux for blast furnaces, while others such as wolframite, pyrolusite and chromite are used in making ferrous alloys.

Important non-ferrous metals include aluminium, copper, lead, nickel, tin, titanium & zinc, and alloys such as brass. Precious metals such as gold, silver and platinum and exotic or rare metals such as cobalt, mercury, tungsten, beryllium, bismuth, cerium, cadmium, niobium, indium, gallium, germanium, lithium, selenium, tantalum, tellurium, vanadium and zirconium, are also non-ferrous. They are usually obtained through minerals such as sulphides, carbonates, and silicates. Non-ferrous metals are usually refined through electrolysis.

Recycling and Pollution Control

Due to their extensive use, non-ferrous scrap metals are usually recycled. The secondary materials in scrap are vital to the metallurgy industry, as the production of new metals often needs them. Some recycling facilities re-smelt and recast non-ferrous materials; the dross is collected and stored onsite while the metal fumes are filtered and collected. Non-ferrous scrap metals are sourced from industrial scrap materials, particle emissions and obsolete technology (for example, copper cables scrap).

Ancient History

Non-ferrous metals were the first metals used by humans for metallurgy. Gold, silver and copper existed in their native crystalline yet metallic form. These crystals, though rare, are enough to attract the attention of humans. Less susceptible to oxygen than most other metals, they can be found even in weathered outcroppings. Copper was the first metal to be forged; it was soft enough to be fashioned into various objects by cold forging, and it could be melted in a crucible. Gold, silver and

copper replaced some of the functions of other resources, such as wood and stone, owing to their ability to be shaped into various forms for different uses. Due to their rarity, these gold, silver and copper artifacts were treated as luxury items and handled with great care. The use of copper also heralded the transition from the Stone Age to the Copper Age. The Bronze Age, which succeeded the Copper Age, was again heralded by the invention of bronze, an alloy of copper with the non-ferrous metal tin.

Mechanical and Structural Use

It is used in residential, commercial, and industrial sectors. Material selection for a mechanical or structural application requires some important considerations, including how easily the material can be shaped into a finished part and how its properties can be either intentionally or inadvertently altered in the process. Depending on the end use, metals can be simply cast into the finished part, or cast into an intermediate form, such as an ingot, then worked or wrought, by rolling, forging, extruding, or other deformation process. Although the same operations are used with ferrous as well as non-ferrous metals and alloys, the reaction of non-ferrous metals to these forming processes is often more severe. Consequently, properties may differ considerably between the cast and wrought forms of the same metal or alloy.

Non-Ferrous Extractive Metallurgy

It is one of the two branches of extractive metallurgy which pertains to the processes of reducing valuable, non-iron metals from ores or raw material. Metals like zinc, copper, lead, aluminium as well as rare and noble metals are of particular interest in this field, while the more common metal, iron, is considered a major impurity. Like ferrous extraction, non-ferrous extraction primarily focuses on the economic optimization of extraction processes in separating qualitatively and quantitatively marketable metals from its impurities (gangue).

Any extraction process will include a sequence of steps or unit processes for separating highly pure metals from undesirables in an economically efficient system. Unit processes are usually broken down into three categories: pyrometallurgy, hydrometallurgy and electrometallurgy. In pyrometallurgy, the metal ore is first oxidized through roasting or smelting. The target metal is further refined at high temperatures and reduced to its pure form. In hydrometallurgy, the object metal is first dissociated from other materials using a chemical reaction, which is then extracted in pure form using electrolysis or precipitation. Finally, electrometallurgy generally involves electrolytic or electrothermal processing. The metal ore is either distilled in an electrolyte or acid solution, then magnetically deposited onto a cathode plate (electrowinning); or smelted then melted using an electric arc or plasma arc furnace (electrothermic reactor). Extractive metallurgy of ferrous and non-ferrous metals can involve pyrometallurgy, but chemical processes like hydrometallurgy and electrometallurgy are far more common in method of non-ferrous extraction.

Another major difference in non-ferrous extraction is the greater emphasis on minimizing metal losses in slag. This is widely due to the exceptional scarcity and economic value of certain non-ferrous metals which are inevitably discarded during the extraction process to some extent. Thus, material resource scarcity and shortages are of great concern to the non-ferrous industry. Recent developments in non-ferrous extractive metallurgy now emphasize on the reprocessing and recycling of rare and non-ferrous metals from secondary raw materials (scrap) found in landfills.

Prehistory of Non-Ferrous Extractive Metallurgy

In general, prehistoric extraction of metals, particularly copper, involved two fundamental stages: first, the smelting of copper ore at temperatures exceeding 700°C is needed to separate the gangue from the copper; second, melting the copper, which requires temperatures exceeding its melting point of 1080°C. Given the available technology at the time, accomplishing these extreme temperatures posed a significant challenge. Early smelters developed ways to effectively increase smelting temperatures by feeding the fire with forced flows of oxygen.

Copper extraction in particular, is of great interest in archeometallurgical studies since it dominated other metals in Mesopotamia from the early Chalcolithic until the mid-to-late sixth century BC. There is a lack of consensus among archeometallurgists on the origin of non-ferrous extractive metallurgy. Some scholars believe that extractive metallurgy may have been simultaneously or independently discovered in several parts of the world. The earliest known use of pyrometallurgical extraction of copper occurred in Belovode, eastern Serbia, from the late sixth to early fifth millennium BC. However, there is also evidence of copper smelting in Tal-i Iblis south-eastern Iran, which dates back to around the same period. During this period, copper smelters used large in-grown pits filled with coal, or crucibles to extract copper, but by the fourth millennium BC, this practice had begun to phase out in favour of the smelting furnace, which had a larger production capacity. From the third millennium onward, the invention of the reusable smelting furnace was crucial to the success of large-scale copper production and the robust expansion of the copper trade through the Bronze Age.

The earliest silver objects began appearing in the late fourth millennium BC in Anatolia, Turkey. Prehistoric silver extraction is strongly associated with the extraction of the less valuable metal, lead; although evidence of lead extraction technology predates silver by at least 3 millennia. Silver and lead extractions are also associated because the argentiferous (silver-bearing) ores used in the process often contains both elements.

In general, prehistoric silver recovery was broken down into three phases: First, the silver-lead ore is roasted to separate the silver and lead from the gangue. The metals are then melted at high temperature (greater than 1100°C) in the crucible, while air is blown over the molten metal (cupellation). Finally, lead is oxidized to form lead monoxide (PbO) or is absorbed into the walls of the crucible, leaving the refined silver behind.

The silver-lead cupellation method was first used in Mesopotamia between 4000 and 3500 BC. Silver artifacts, dating around 3600 BC, were discovered in Naqada, Egypt. Some of these cast silver artifacts contained less than 0.5 per cent lead, which strongly indicates cupellation.

Early to late Anglo-Saxon Cupellation



Medieval Smelting Plant

Cupellation was also being used in parts of Europe to extract gold, silver, zinc, and tin by the late ninth to tenth century AD. Here, one of the earliest examples of an integrated unit process for extracting more than one precious metal was first introduced by Theophilus around the twelfth century. First, the gold-silver ore is melted down in the crucible, but with an excess amount of lead. The intense heat then oxidizes the lead which reacts quickly and binds with the impurities in the gold-silver ore. Since both gold and silver have low reactivity with the impurities, they remain behind once the slag is removed. The last stage involves parting, in which the silver is separated from the gold. First, the gold-silver alloy is hammered into thin sheets and placed into a vessel. The sheets were then covered in urine, which contains sodium chloride (NaCl). The vessel is then capped and heated for several hours until the chlorides bind with the silver, creating silver chloride (AgCl). Finally, the silver chloride powder is then removed and smelted to recover the silver, while the pure gold remains intact.

Hydrometallurgy in Chinese Antiquity

During the Song Dynasty, Chinese copper output from domestic mining was in decline and the resulting shortages caused miners to seek alternative methods for extracting copper. The discovery of a new "wet process" for extracting copper from mine water was introduced between the eleventh and twelfth century, which helped to mitigate their loss of supply.

Similar to the Anglo-Saxon method for cupellation, the Chinese employed the use of a base metal to extract the target metal from its impurities. First the base metal iron, is hammered into thin sheets. The sheets are then placed into a trough filled with "vitriol water" i.e., copper mining water which is then left to steep for several days. The mining water contains copper salts in the form of copper sulphate $CuSO_4$. The iron then reacts with the copper, displacing it from the sulphate ions, causing the copper to precipitate onto the iron sheets, forming a "wet" powder. Finally, the precipitated copper is collected and refined further through the traditional smelting process. This is the first large-scale use of a hydrometallurgical process.

Non-Ferrous Metals

Non-ferrous metals offer a wide variety of mechanical properties and material characteristics. They are specified for structural applications requiring reduced weight, higher strength, nonmagnetic properties, higher melting points, or resistance to chemical and atmospheric corrosion. They are also specified for electrical and electronic applications.

Material selection for a mechanical or structural application requires some important considerations, including how easily the material can be shaped into a finished part and how its properties can be either intentionally or inadvertently altered in the process.

To shape both non-ferrous and ferrous metals, designers use processes that range from casting and sintered powder metallurgy (P/M) to hot and cold working. Each forming method imparts unique physical and mechanical characteristics to the final component.

Aluminium

Though light in weight, commercially pure aluminium has a tensile strength of about 13,000 psi. Cold working the metal approximately doubles its strength. In other attempts to increase strength, aluminium is alloyed with elements such as manganese, silicon, copper, magnesium, or zinc. The alloys can also be strengthened by cold working. Some alloys are further strengthened and hardened by heat treatments. At subzero temperatures, aluminium is stronger than at room temperature and is no less ductile. Most aluminium alloys lose strength at



elevated temperatures, although some retain significant strength to 500°F. Besides a high strength-to-weight ratio and good formability, aluminium also possesses its own anticorrosion mechanism. When exposed to air, aluminium does not oxidize progressively because a hard, microscopic oxide coating forms on the surface and seals the metal from the environment. The tight chemical oxide bond is the reason that aluminium is not found in nature: it exists only as a compound.

Aluminium and its alloys, numbering in the hundreds, are available in all common commercial forms. Aluminium-alloy sheet can be formed, drawn, stamped, or spun. Many wrought or cast aluminium alloys can be welded, brazed, or soldered, and aluminium surfaces readily accept a wide variety of finishes, both mechanical and chemical. Because of their high electrical conductivity, aluminium alloys are used as electrical conductors. Aluminium reflects radiant energy throughout the entire spectrum, is non-sparking, and nonmagnetic.

Wrought Aluminium: A four-digit number that corresponds to a specific alloying element combination usually designates wrought aluminium alloys. This number is followed by a temper designation that identifies thermal and mechanical treatments.

To develop strength, heat-treatable wrought alloys are solution heat treated, then quenched and precipitation hardened. Solution heat treatment consists of heating the metal, holding at temperature to bring the hardening constituents into solution, then cooling to retain those constituents in solution. Precipitation hardening after solution heat treatment increases strength and hardness of these alloys.

While some alloys age at room temperature, others require precipitation heat treatment at an elevated temperature (artificial aging) for optimum properties. However, distortion and dimensional changes during natural or artificial aging can be significant. In addition, distortion and residual stresses can be introduced during quenching from the solution heat-treatment cycle. These induced changes can be removed by deforming the metal (for example, stretching).

Wrought aluminium alloys are also strengthened by cold working. The high-strength alloys — either heat treatable or not — work harden more rapidly than the lower-strength, softer alloys and so, may require annealing after cold working. Because hot forming does not always work harden aluminium alloys, this method is used to avoid annealing and straightening operations; however, hot forming fully heat-treated materials is difficult. Generally, aluminium formability increases with temperature.

Recently developed aluminium alloys can provide nearly custom-engineered strength, fracture toughness, fatigue resistance, and corrosion resistance for aircraft forgings and other critical components. The rapid-solidification process is the basis for these new alloy systems, called wrought P/M alloys. The term wrought P/M is used to distinguish this technology from conventional press-and-sinter P/M technology. Grades 7090 and 7091 are the first commercially available wrought P/M aluminium alloys. These alloys can be handled like conventional aluminium alloys on existing aluminium-fabrication facilities.

Other significant new materials are the aluminium-lithium alloys. These lightweight metals are as strong as alloys now in use and can be fabricated on existing metalworking equipment. Although impressive structural weight reductions (from 7 to 10 per cent) are possible through direct substitution, even greater reduction (up to 15 per cent) can be realized by developing fully optimized alloys for new designs. Such alloys would be specifically tailored to provide property combinations not presently available. Producing an alloy that will provide these combinations is the object of second and third-generation low-density alloy development efforts.

Operating economy is still an important consideration in vehicle design despite fluctuating fuel prices. Downsizing to save fuel has reached its practical limits; now, reducing the weight of individual components is taking over. One significant change being implemented by designers of automobiles and military vehicles today is converting driveshafts, radiators, cylinder heads, suspension members, and other structural components to aluminium.

Cast Aluminium: Aluminium can be cast by all common casting processes. Aluminium casting alloys are identified with a unified, four-digit (xxx.x) system. The first digit indicates the major alloying element. For instance, 100 series is reserved for 99 per cent pure aluminium with no major alloying element used. The second and third digits in the 100 series indicate the precise minimum aluminium content. For example, 165.0 have a 99.65 per cent minimum aluminium content. The 200-900 series designate various aluminium alloys, with the second two digits assigned to new alloys as they are registered. The fourth digit indicates the product form. Castings are designated 0; ingots are designed 1 or 2.

Letter prefixes before the numerical designation indicate special control of one or more elements or a modification of the original alloy. Prefix X designates an experimental composition. The material may retain the experimental designation up to five years. Limits for the experimental alloy may be changed by the registrant.

Commercial casting alloys include heat-treatable and nonheat-treatable compositions. Alloys that are heat treated carry the temper designations 0, T4, T5, T6, and T7. Die castings are not usually solution heat treated because the temperature can cause blistering.

Permanent-mold casting technology involves several variations having to do with how the metal gets into the mold cavity. Initially, molds were simply gravity filled from ladles, in the same manner as sand molds. Subsequently, low pressure on the liquid-metal surface of a crucible was used to force the metal up, through a vertical tube, into the mold cavity. This refinement produces castings with higher mechanical properties and is more economical than gravity filling because extensive gates and risers are unnecessary.

More recently, the process was modified to use a low level of vacuum drawn on the mold cavity, causing atmospheric pressure to force the molten metal up into the mold. This process

variation, together with controlled and rapid solidification, increases properties further because it produces castings that are almost entirely free of porosity.

Although both variations improve properties and speed casting cycles, the added equipment complexities limit the casting size that can be handled. Consequently, all three permanent-mold processes are in use today, turning out aluminium castings weighing from less than one pound to several hundred pounds.

Aluminium Matrix Composites: Metal matrix composites (MMCs) consist of metal alloys reinforced with fibers, whiskers, particulates, or wires. Alloys of numerous metals (aluminium, titanium, magnesium and copper) have been used as matrices to date. Recent MMC developments, however, seem to thrust aluminium into the spotlight. In the NASA space shuttle, for example, 240 struts are made from aluminium reinforced with boron fibers. Also, aluminium diesel-engine pistons that have been locally reinforced with ceramic fibers are eliminating the need for wear-resistant nickel-cast iron inserts in the automotive environment.

Fabrication methods differ for both products. Monolayer tapes in the space shuttle struts are wrapped around a mandrel and hot isostatically pressed to diffusion bond the layers. For the pistons, a squeeze-casting process infiltrates liquid metal into a fiber preform under pressure. Other fabrication methods for MMCs include: hot pressing a layer of parallel fibers between foils to create a monolayer tape; creep and super plastic forming in a die; and spraying metal plasmas on collimated fibers followed by hot pressing.

Super Plastic Aluminium: Super plastic forming of metal, a process similar to vacuum forming of plastic sheet, has been used to form low-strength aluminium into nonstructural parts such as cash-register housings, luggage compartments for passenger trains, and nonload-bearing aircraft components. New in this area of technology is a super plastic-formable high-strength aluminium alloy, now available for structural applications and designated 7475-02. Strength of alloy 7475 is in the range of aerospace alloy 7075, which requires conventional forming operations. Although initial cost of 7475 is higher, finished part cost is usually lower than that of 7075 because of the savings involved in the simplified design/assembly.

Beryllium

Among structural metals, beryllium has a unique combination of properties. It has low density (two-thirds that of aluminium), high modulus per weight (five times that of ultrahigh-strength steels), high specific heat, high strength per density, excellent dimensional stability, and transparency to X-rays. Beryllium is expensive, however, and its impact strength is low compared to values for most other metals. Available forms include block, rod, sheet, plate, foil, extrusions, and wire. Machining blanks, which are machined from large vacuum hot pressings, make up the majority of beryllium purchases. However, shapes can also be produced directly from powder by processes such as cold-press/sinter/coin, CIP/HIP, CIP/sinter, CIP/hot-press and plasma spray/sinter. CIP is cold-isostatic press, and HIP is hot-isostatic press. Mechanical properties depend on powder characteristics, chemistry, consolidation process, and thermal treatment. Wrought forms, produced by hot working, have high strength in the working direction, but properties are usually anisotropic.



Beryllium parts can be hot formed from cross-rolled sheet and plate as well as plate machined from hot-pressed block. Forming rates are slower than for titanium, for example, but tooling and forming costs for production items are comparable. Structural assemblies of beryllium components can be joined by most techniques such as mechanical fasteners, rivets, adhesive bonding, brazing, and diffusion bonding. Fusion-welding processes are generally avoided because they cause excessive grain growth and reduced mechanical properties.

Beryllium behaves like other light metals when exposed to air by forming a tenacious protective oxide film that provides corrosion protection. However, the bare metal corrodes readily when exposed for prolonged periods to tap or seawater or to a corrosive environment that includes high humidity. The corrosion resistance of beryllium in both aqueous and gaseous environments can be improved by applying chemical conversion, metallic, or nonmetallic coatings. Beryllium can be electroless nickel plated, and flame or plasma sprayed.

All conventional machining operations are possible with beryllium, including EDM and ECM. However, beryllium powder is toxic if inhaled. Since airborne beryllium particles and beryllium salts present a health hazard, the metal must be machined in specially equipped facilities for safety. Machining damages the surface of beryllium parts. Strength is reduced by the formation of micro cracks and "twinning." The depth of the damage can be limited during finish machining by taking several light machining cuts and sharpening cutting tools frequently or by using nonconventional metal-removal processes. For highly stressed structural parts, 0.002 to 0.004 in. should be removed from each surface by chemical etching or milling after machining. This process removes cracks and other surface damage caused by machining, thereby preventing premature failure. Precision parts should be machined with a sequence of light cuts and intermediate thermal stress reliefs to provide the greatest dimensional stability.

Beryllium typically appears in military-aircraft and space-shuttle brake systems, in missile re-entry body structures, missile guidance systems, mirrors and optical systems, satellite structures, and X-ray windows. The modulus-to-density ratio is higher than that of unidirectionally reinforced, "high-modulus" boron, carbon, and graphite-fiber composites. Beryllium has an additional advantage because its modulus of elasticity is isotropic.

Copper

Copper conducts electricity at a rate 97 per cent that of silver, and is the standard for electrical conductivity. Copper provides a diverse range of properties: good thermal and electrical conductivity, corrosion resistance, ease of forming, ease of joining, and colour. In addition, however, copper and its alloys have relatively low strength-to-weight ratios and low strengths at elevated temperatures. Some copper alloys are also susceptible to stress-corrosion cracking unless they are stress relieved.



Copper and its alloys — the brasses and bronzes — are available in rod, plate, strip, sheet, tube shapes, forgings, wire, and castings. These metals are grouped according to composition into several general categories: coppers, high-copper alloys, brasses, leaded brasses, bronzes, aluminium bronzes, silicon bronzes, copper nickels, and nickel silvers.

Copper-based alloys form adherent films that are relatively impervious to corrosion and that protect the base metal from further attack. Certain alloy systems darken rapidly from brown to black in air. Under most outdoor conditions, however, copper surfaces develop a blue-green patina. Lacquer coatings can be applied to retain the original alloy colour. An acrylic coating with benzotriazole as an additive lasts several years under most outdoor, abrasion-free conditions.

Although they work harden, copper and its alloys can be hot or cold worked. Ductility can be restored by annealing or heating incident to welding or brazing operations. For applications requiring maximum electrical conductivity, the most widely used copper is C11000, "tough pitch," which contains approximately 0.03 per cent oxygen and a minimum of 99.0 per cent copper. In addition to high electrical conductivity, oxygen-free grades C10100 and C10200 provide immunity to embrittlement at high temperature. The addition of phosphorous produces grade C12200 — the standard water-tube copper.

High-copper alloys contain small amounts of alloying elements that improve strength with some loss in electrical conductivity. In amounts of 1 per cent, for example, cadmium increases strength by 50 per cent, with a loss in conductivity to 85 per cent. Small amounts of cadmium raise the softening temperature in alloy C11600, which is used widely for printed circuits. Tellurium or sulphur, present in small amounts in Grades C14500 and C14700, has been shown to increase machinability.

Copper alloys do not have a sharply defined yield point, so yield strength is reported either as 0.5 per cent extension under load or as 0.2 per cent offset. On the most common basis (0.5 per cent extension), yield strength of annealed material is approximately one-third the tensile strength. As the material is cold worked or hardened, it becomes less ductile, and yield strength approaches tensile strength.

Copper is specified according to temper, which is established by cold working or annealing. Typical levels are: soft, half-hard, hard, spring, and extra-spring. Yield strength of a hard-temper copper is approximately two-thirds of tensile strength.

For brasses, phosphor bronzes, or other commonly cold-worked grades, the hardest available tempers are also the strongest and represent approximately 70 per cent reduction in area. Ductility is sacrificed, of course, to gain strength. Copper-beryllium alloys can be precipitation hardened to the highest strength levels attainable in copper-base alloys.

The ASME Boiler and Pressure Vessel Code should be used for designing critical copper-alloy parts for service at elevated temperatures. The code recommends that, for a specific service temperature, the maximum allowable design stress should be the lowest of these values as tabulated by the code: one-fourth of the ultimate tensile strength, two-thirds of the yield strength, and two-thirds of the average creep strength or stress-rupture strength under specified conditions. Silicon bronzes, aluminium brasses, and copper nickels are widely used for elevated-temperature applications.

All copper alloys resist corrosion by fresh water and steam. Copper nickels, aluminium brass, and aluminium bronzes provide superior resistance to saltwater corrosion. Copper alloys have high resistance to alkalis and organic acids, but have poor resistance to inorganic acids. One corrosive situation encountered, particularly in the high-zinc alloy, is dezincification. The brass dissolves as an alloy, but the copper constituent redeposits as a porous, spongy metal. Meanwhile, the zinc component is carried away by the atmosphere or deposited on the surface as an insoluble compound.

Designating Alloys: Originally developed as a three-digit system by the US copper and brass industry, the designation system for copper-based alloys has been expanded to five digits preceded by the letter C as part of the Unified Numbering System for Metals and Alloys (UNS). The UNS designations are simply an expansion of the former designation numbers. For example,

Copper Alloy No. 377 (forging brass) becomes C37700. Numbers C10000 through C79900 are assigned to wrought compositions, and numbers C80000 through C99900 to casting alloys.

The designation system is not a specification; rather, it is a method for identifying and defining the chemical composition of mill and foundry products. The precise requirements to be satisfied by a material and the temper nomenclature that applies are defined by the relevant standard specifications (ASTM, Federal, and Military) for each composition.

There are approximately 370 commercial copper and copper-alloy compositions. Brass mills make wrought compositions in the form of rod, plate, sheet, strip, tube, pipe, extrusions, foil, forgings, and wire. Foundries supply castings. The following general categories apply to both wrought and cast compositions.

Coppers, High-Copper Alloys: Both wrought and cast compositions have a designated minimum copper content and may include other elements or additions for special properties.

Brasses: These alloys contain zinc as the principal alloying element and may have other designated elements. The wrought alloys are comprised of copper-zinc alloys, copper-zinc-lead alloys (leaded brasses), and copper-zinc-tin alloys (tin brasses). The cast alloys are comprised of copper-zinc-tin alloys (red, semi-red and yellow brasses), manganese bronze alloys (high-strength yellow brasses), leaded manganese bronze alloys (leaded high-strength yellow brasses), and copper-zinc-silicon alloys (silicon brasses and bronzes).

Bronzes: Wrought bronze alloys comprise four main groups: copper-tin-phosphorous alloys (phosphor bronzes), copper-tin-lead-phosphorous alloys (leaded phosphor bronzes), and copper-silicon alloys (silicon bronzes). Cast alloys also have four main families: copper-tin alloys (tin bronzes), copper-tin-lead alloys (leaded and high-leaded tin bronzes), copper-tin-nickel alloys (nickel-tin bronzes), and copper-aluminium alloys (aluminium bronzes).

Copper-Nickels: These are either wrought or cast alloys containing nickel as the principal alloying element.

Copper-Nickel-Zinc Alloys: These are known as nickel silvers, from their colour.

Leaded Coppers: These are cast alloys containing 20 per cent lead or more.

Magnesium

As the lightest structural metal available, magnesium's combination of low density and good mechanical strength results in a high strength-to-weight ratio.

Because of their low modulus of elasticity, magnesium alloys can absorb energy elastically. Combined with moderate strength, this provides excellent dent resistance and high damping capacity. Magnesium has good fatigue resistance and performs particularly well in applications involving a large number of cycles at relatively low stress. The metal is sensitive to stress concentration, however so, notches, sharp corners, and abrupt section changes should be avoided.



Magnesium parts are generally used from room temperature to about 200°F or, in some cases, to 350°F. Some alloys can be used in service environments to 700°F for brief exposures.

Magnesium is widely recognized for its favourable strength-to-weight ratio and excellent castability, but deeply ingrained misconceptions often prevent designers from specifying it as a die-cast material. However, what is true of magnesium as a generic material is not true of today's die-casting alloy. The new high-purity alloy, combined with advances in fluxless, hot-chamber die-casting processing, has altered the traditional guidelines for evaluating the cost and performance of magnesium die castings.

Cast magnesium alloys are dimensionally stable to about 200°F. Some cast magnesium-aluminium-zinc alloys may undergo permanent growth if used above that temperature for long periods. Permanent-mold castings are as strong as sand castings, and they generally provide closer dimensional tolerances and better surface finish. Typical applications of magnesium gravity castings are aircraft engine components and wheels for race and sports cars.

Design of die-cast magnesium parts follows the same principles established for other die-casting metals. Maximum mechanical properties in a typical alloy are developed in wall thicknesses ranging from 0.078 to 0.150 in. Chain-saw and power-tool housings, archery-bow handles, and attaché-case frames are typical die-cast applications.

Magnesium is easy to hot work, so fewer forging steps are usually required than for other metals. Bending, blocking, and finishing are usually the only operations needed. Typical magnesium forgings are missile fuselage connector rings.

Standard extruded shapes include round, square, rectangular, and hexagonal bars; angles, beams, and channels; and a variety of tubes. Luggage frames and support frames for military shelters are examples of magnesium extrusions.

Methods used for joining magnesium are gas tungsten-arc (TIG) and gas metal-arc (MIG) welding, spot welding, riveting, and adhesive bonding. Mechanical fasteners can be used on magnesium, provided that stress concentrations are held to a safe minimum. Only ductile aluminium rivets should be used, preferably alloy 5056-H32, to minimize galvanic-corrosion failure at riveted joints.

Specification: Magnesium alloys are designated by a system established by the ASTM that covers both chemical compositions and tempers.

The first two letters of the designation identifies the two alloying elements specified in the greatest amount. The letters are arranged in order of decreasing percentages or alphabetically if the elements are present in equal amounts. The letters are followed by respective percentages rounded off to whole numbers, followed by a final serial letter. The serial letter indicates some variation in composition of minor alloying constituents or impurities.

The letters that designate the more common magnesium alloying elements are:

- A – Aluminium
- E – Rare Earths
- H – Thorium
- K – Zirconium
- L – Lithium
- M – Manganese
- Q – Silver
- S – Silicon
- Z – Zinc

For example, magnesium alloy AZ31B contains 3 per cent aluminium (code letter A) and 1 per cent zinc (code letter Z).

Resisting corrosion: A problem with magnesium has been its lack of sufficient corrosion resistance for many applications, particularly in the alloys used for die and sand casting. The problem has been solved by the two major supplies, Dow and AMAX; both have developed corrosion-resistant, high-purity AZ91 alloys for die casting, and both also offer a sand-casting grade.

The die-casting grade is now designated by ASTM as AZ91D and will, for all practical purposes, replace AZ91B. The sand-casting grade received the designation AZ91E from ASTM. The high-purity alloys are said to be as much as 100 times more corrosion resistant than standard magnesium alloys, and more resistant to saltwater than die-cast 380 aluminium alloy or cold-rolled steel, tested according to ASTM B117. Research in magnesium metallurgy has shown that the ability of magnesium to resist corrosion in a service environment of salt-laden air or spray depends heavily on keeping contaminants (iron, nickel, copper) below their maximum tolerance limits during all production operations.

The high-purity magnesium die-casting alloy has already replaced other metals as well as a number of plastics in a variety of US passenger-car and lightweight-truck components. Examples include valve and timing-gear covers, brackets, clutch and transfer-case housings, grille panels, headlamp doors, windshield-wiper motor housings, and various interior trim parts.

Nickel

Structural applications that require specific corrosion resistance or elevated temperature strength receive the necessary properties from nickel and its alloys. Some nickel alloys are among the toughest structural materials known. When compared to steel, other nickel alloys have ultrahigh strength, high proportional limits, and high moduli of elasticity. Commercially pure nickel has good electrical, magnetic, and magnetostrictive properties.



Common nickel alloy families include: commercially pure nickel; binary systems, such as Ni-Cu, Ni-Si, and Ni-Mo; ternary systems, such as Ni-Cr-Fe and Ni-Cr-Mo; more complex systems, such as Ni-Cr-Fe-Mo-Cu (with other possible additions); and super alloys. Nickel content throughout the alloy families ranges from 32.5 to 99.5 per cent.

At cryogenic temperatures, nickel alloys are strong and ductile. Several nickel-base super alloys are specified for high strength applications at temperatures to 2,000°F. High carbon nickel base casting alloys are commonly used at moderate stresses above 2,200°F.

Alloy Characteristics: Commercial nickel & nickel alloys are available in wide range of wrought and cast grades; however, considerably fewer casting grades are available. Wrought alloys tend to be better known by trade names such as Monel, Hastelloy, Inconel, Incoloy, etc. Casting alloys are identified by Alloy Casting Institute and ASTM designations. Wrought & cast nickel alloys are often used together in systems built up from wrought & cast components. The casting alloys contain additional elements, such as silicon and manganese, to improve castability and pressure tightness.

Commercially pure nickels and extra high nickel alloys: Primary wrought materials in this group are Nickel 200 and 201, both of which contain 99.5 per cent Ni. The cast grade, designated CZ-100, is recommended for use at temperatures above 600°F because its lower carbon content prevents graphitization and attendant ductility loss. Both wrought grades are particularly resistant to caustics, high-temperature halogens and hydrogen halides, and salts other than oxidizing halides. These alloys are particularly well suited for food-contact applications.

Dura nickel 301, a precipitation-hardened, 94 per cent nickel alloy, has excellent spring properties to 600°F. During thermal treatment, Ni3AlTi particles precipitate throughout the matrix. This action enhances alloy strength. Corrosion resistance is similar to that of commercially pure wrought nickel.

Binary nickel alloys: The primary wrought alloys in this category are the Ni-Cu grades known as Monel alloy 400 (Ni-31.5Cu) and K-500 (Ni-29.5Cu), which also contain small amounts of Al, Fe, and Ti. The Ni-Cu alloys differ from Nickel 200 and 201 because their strength and hardness can be increased by age hardening. Although the Ni-Cu alloys share many of the corrosion characteristics of commercially pure nickel, their resistance to sulphuric and hydrofluoric acids and brine is better. Handling of waters, including seawater and brackish water, is a major application. Monel alloys 400 and K-500 are immune to chloride-ion stress-corrosion cracking, which is often considered in their selection.

Other commercially important binary nickel compositions are Ni-Mo and Ni-Si. One binary type, Hastelloy alloy B-2 (Ni-28Mo), offers superior resistance to hydrochloric acid, aluminium-chloride catalysts, and other strongly reducing chemicals. It also has excellent high-temperature strength in inert atmospheres and vacuum.

Cast nickel-copper alloys comprise a low high silicon grade. M-35-1 and QQ-N-288, Grades A and E (1.5% Si), are commonly used in conjunction with wrought nickel-copper in pumps, valves, and fittings. A higher silicon grade, QQ-N-288, Grade B (3.5%Si), is used for rotating parts and wear rings because it combines corrosion resistance with high strength and wear resistance. Grade D (4.0% Si) offers exceptional galling resistance.

Two other binary cast alloys are ACI N-12 M-1 and N-12 M-2. These Ni-Mo alloys are commonly used for handling hydrochloric acid in all concentrations at temperatures up to boiling point. These alloys are produced commercially under the trade names Hastelloy alloy B and Chlorimet 2.

Ternary nickel alloys: Two primary wrought and cast compositions are Ni-Cr-Fe and Ni-Cr-Mo. Ni-Cr-Fe is known commercially as Haynes alloys 214 and 556, Inconel alloy 600, and Incoloy alloy 800. Haynes new alloy No. 214 (Ni-16Cr-2.5Fe-4.5Al-Y) has excellent resistance to oxidation to 2,200°F, and resists carburizing and chlorine-contaminated atmospheres. Haynes patented alloy No. 556 (Fe-20Ni-22Cr-18Co) combine effective resistance to sulphidizing, carburizing, and chlorine-bearing environments with good oxidation resistance, fabricability and high-temperature strength. Inconel alloy 600 (Ni-15.5Cr-8Fe) has good resistance to oxidizing and reducing environments. Intended for severely corrosive conditions at elevated temperatures, Incoloy 800 (Ni-46Fe-21Cr) has good resistance to oxidation and carburization at elevated temperatures, and it resists sulphur attack, internal oxidation, scaling, and corrosion in many atmospheres.

A cast Ni-Cr-Fe alloy CY-40, known as Inconel, has higher carbon, Mn, and Si contents than the corresponding wrought grade. In the as-cast condition, the alloy is insensitive to the type of Intergranular attack encountered in as-cast or sensitized stainless steels.

Significant additions of molybdenum make Ni-Cr-Mo alloys highly resistant to pitting. They retain high strength and oxidation resistance at elevated temperatures, but they are used in the chemical industry primarily for their resistance to a wide variety of aqueous corrosives. In many applications, these alloys are considered the only materials capable of withstanding the severe corrosion conditions encountered.

In this group, the primary commercial materials are C-276, Hastelloy alloy C-22, and Inconel alloy 625. Hastelloy alloy C-22 (Ni-22Cr-13Mo-3W-3Fe) has better overall corrosion resistance and versatility than any other Ni-Cr-Mo alloy. Alloy C-276 (57Ni-15.5Cr-16Mo) has excellent resistance to strong oxidizing and reducing corrosives, acids, and chlorine-contaminated hydrocarbons. Alloy C-276 is also one of the few materials that withstand the corrosive effects of wet chlorine gas, hypochlorite, and chlorine dioxide. Hastelloy alloy C-22, the newest alloy in this group, has outstanding resistance to pitting, crevice corrosion, and stress-corrosion cracking. Present applications include the pulp and paper industry, various pickling acid processes, and production of pesticides and various agrichemicals.

Two grades of cast Ni-Cr-Mo alloy, ACI CW-12M-1 and CW-12M-2, are used in severe corrosion service, often involving combinations of acids at elevated temperatures. The two versions of CW-12M are also produced as Hastelloy C and Chlorimet.

Complex Alloys: Ni-Cr-Fe-Mo-Cu is the basic composition in this category of nickel alloys. They offer good resistance to pitting. Intergranular corrosion, chloride-ion stress-corrosion cracking, and general corrosion in a wide range of oxidizing & reducing environments. These alloys are frequently used in applications involving sulphuric and phosphoric acids.

Important commercial grades include Hastelloy alloys G-30 and H, Haynes alloy No. 230, Inconel alloys 617, 625 & 718, and Incoloy alloy 825.

Haynes alloy No. 230 (Ni-22Cr-14W-2Mo) has excellent high-temperature strength, oxidation resistance, and thermal stability, making it suitable for various applications in the aerospace, airframe, nuclear, and chemical-process industries.

Hastelloy alloy G-30 (Ni-30Cr-6Mo-2.5W-15Fe) has many advantages over other metallic and nonmetallic materials in handling phosphoric acid, sulphuric acid, and oxidizing acid mixtures. Hastelloy alloy H (Ni-22Cr-9Mo-2W-18Fe) is a patented alloy with localized corrosion resistance equivalent or better to alloy 625. Alloy H also has good resistance to hot acids and excellent resistance to stress-corrosion cracking. It is often used in flue gas desulphurization equipment.

Inconel alloy 617 (Ni-22Cr-12.5Co-9Mo-1.5Fe-1.2 Al) resists cyclic oxidation at 2,000°F, and has good stress-rupture properties above 1,800°F.

Inconel alloy 625 (Ni-21.5Cr-2.5Fe-9Mo-3.6Nb+Ta) has high strength and toughness from cryogenic temperatures to 1,800°F, good oxidation resistance, exceptional fatigue strength,

and good resistance to many corrosives. Furnace mufflers, electronic parts, chemical and food-processing equipment, and heat-treating equipment are among a few of the many applications for alloy 615.

Inconel alloy 718 (Ni-18.5Fe-19Cr-3Mo-5Nb+Ta) has excellent strength from -423 to 1,300°F. The alloy is age hardenable, can be welded in the fully aged condition, and has excellent oxidation resistance up to 1,800°F.

Incoloy 825 (42Ni-30Fe-21.5Cr-3Mo-2.25Cu) offers excellent resistance to a wide variety of corrosives. It resists pitting and Intergranular corrosion, reducing acids, and oxidizing chemicals. Applications include pickling – tank heaters and hooks, spent nuclear-fuel-element recovery, chemical-tank trailers, evaporators, food processing equipment, sour-well tubing, hydrofluoric-acid production, pollution control equipment, and radioactive-waste systems.

Super Alloys: One class of Ni-based super alloys is strengthened by inter-metallic compound precipitation in a face-centered cube matrix. The strengthening precipitate is gamma prime, typified by Waspaloy (Ni-19.5Cr-13.5Co-4.3Mo-3.0Ti-1.4Al-2.0Fe). Udimet 700 (Ni-15Cr-18.5Co-5Mo-3.4Ti-4.3Al- <1Fe), and the modern but complex Rene 95 (Ni-14Cr-8Co-3.5Mo-3.5W-3.5Nb-2.5Ti-3.5Al).

Another type of Ni-based super alloy is represented by Hastelloy alloy X (Ni-22Fe-9Mo-22Cr-1.5Co). This alloy is essentially solid-solution strengthened, but probably also derives some strengthening from carbide precipitation through a working-plus-aging schedule.

A third class includes oxide-dispersion-strengthened (ODS) alloys such as IN MA-754 (Ni-20Cr-0.6yttria) and IN MA-6000 (Ni-15Cr-2Mo-4W-2.5Ti-4.5Al), which are strengthened by dispersions such as yttria coupled (in some cases) with gamma prime precipitation (MA-6000).

Nickel-based super alloys are used in cast and wrought forms, although special processing (power metallurgy/isothermal forging) often is used to produce wrought versions of the more highly alloyed compositions (U-700, Astroloy, IN-100).

An additional dimension of Ni-based super alloys has been the introduction of grain-aspect ratio and orientation as a means of controlling properties. In some instances, grain boundaries have been removed. Wrought powder-metallurgy alloys of the ODS class and cast alloys such as MAR M-247 have demonstrated property improvements due to grain morphology control by directional crystallization or solidification. Virtually all uses of the cast and wrought nickel-base super alloys are for gas-turbine components.

Fabrication: Most wrought-nickel alloys can be hot and cold worked, machined, and welded successfully. The casting alloys can be machined or ground and many can be welded and brazed.

Nearly any shape that can be forged in steel can also be forged in nickel and nickel alloys. However because nickel work hardens easily, severe cold forming operations require frequent intermediate annealing to restore soft temper. Annealed cold-rolled sheet, not stretcher leveled, is best for spinning and other manual work. In general, cold-drawn rods machine much more cleanly and readily than hot-rolled or annealed material.

Nickel alloys can be joined by shielded metal-arc, gas tungsten-arc, gas metal-arc, plasma-arc, electron-beam, oxyacetylene, and resistance welding; silver & bronze brazing; and soft soldering. Resistance welding methods include spot, seam, projection, and flash welding.

Special nickel alloys, including super alloys are best worked at about 1,800 to 2,200°F. In the annealed condition, these alloys can be cold worked by all standard methods. Required forces and rate of work hardening are intermediate between those of mild steel and type 304 stainless steel. These alloys work harden to a greater extent than the austenitic stainless steels, so they require more intermediate annealing steps.

Both cold-worked and hot-worked Ni-Cu requires thermal treatment to develop optimum ductility and to minimize distortion during subsequent machining. Stress relieving before machining is recommended to minimize distortion after metal removal. Stress equalizing of cold-worked Cu-Ni increases yield strength without marked effects on other properties.

Many Hastelloy alloys can be upset forged if the length of the piece is no greater than twice its diameter. However, upsetting should never be attempted on a cast ingot. Cast ingots must be reduced at least 75 per cent before hot upsetting.

Most wrought nickel-based alloys can be formed from sheet into complex shapes involving considerable plastic flow. These alloys are processed in the annealed condition.

Refractory Metals

Refractory metals are characterized by their extremely high melting points, which range well above those of iron, cobalt, and nickel. They are used in demanding applications requiring high-temperature strength and corrosion resistance. The most extensively used of these metals are tungsten, tantalum, molybdenum, and columbium (niobium). They are mutually soluble and form solid-solution alloys with each other in any proportion. These four refractory metals and their alloys are available in mill forms as well as products such as screws, bolts, studs, and tubing.

Although the melting points of these metals are all well above 4,000°F, they oxidize at much lower temperatures. Accelerated oxidation in air occurs at 190°C for tungsten, 395°C for molybdenum, and 425°C for tantalum and columbium. Therefore, protective coatings must be applied to these metals if they are to be used at higher temperatures. Tensile and yield strengths of the refractory metals are substantially retained at high temperature.

Columbium and Tantalum: These metals are usually considered together because most of their working characteristics are similar. They can be fabricated by most conventional methods at room temperature. Heavy sections for forging can be heated, without protection, to approximately 425°C.

Out of several commercial-grade tantalum alloys, those containing tungsten, columbium, and molybdenum generally retain the corrosion resistance of tantalum and provide higher mechanical properties. Columbium is also available in alloys containing tantalum, tungsten, molybdenum, vanadium, hafnium, zirconium, or carbon. Alloys provide improved tensile, yield, and creep properties, particularly in the 1,100 to 1,650°C range.

Most sheet-metal fabrication of columbium and tantalum is done in the thickness range of 0.004 to 0.060 in. Columbium, like tantalum, can be welded to itself and to certain other metals by resistance welding, tungsten inert-gas (TIG) welding and to itself by inert-gas arc welding. Electron-beam welding can also be used, particularly for joining to other metals. However, surfaces that are heated above 315°C during welding must be protected with an inert gas to prevent embrittlement.

Principal applications of tantalum are in capacitor anodes, filaments, guttering devices, chemical process equipment, and high-temperature aerospace engine components. Columbium is used in superconducting materials, thin-film substrates, electrical contacts, heat sinks, and as an alloying addition in steels and super alloys.

Molybdenum: Probably the most versatile of the refractory metals, molybdenum, is also a natural resource of the United States. It is an excellent structural material for applications requiring high strength & rigidity at temperatures to 3,000°F where it can operate in vacuum or under inert or reducing atmospheres.



Unalloyed molybdenum and its principal alloy, TZM, are produced by powder-metallurgy methods and by vacuum-arc melting. Both are commercially available in ordinary mill product forms: forging billets, bars, rods, wire, seamless tubing, plate, strip, and thin foil. Compared to unalloyed molybdenum, the TZM alloy (Mo-0.5%Ti-0.1%Zr) develops higher strength at room temperature and much higher stress-rupture and creep properties at all elevated temperatures. At 1,800 to 2,000°F, TZM can sustain a 30,000-psi stress for over 100 hrs., three times that for unalloyed molybdenum.

Molybdenum and TZM are readily machined with conventional tools. Sheet can be processed by punching, stamping, spinning, and deep drawing. Some parts can be forged to shape. Molybdenum wire and powder can be flame sprayed onto steel substrates to salvage worn parts or to produce long-wearing, low-friction surfaces for tools.

In non-oxidizing environments, the metal resists attack by hydrochloric, hydrofluoric, sulphuric, and phosphoric acids. Molybdenum oxidizes at high temperatures to produce volatile, nontoxic, molybdenum trioxide; however, parts such as gimbled nozzles have been used successfully in rocket and missile-guidance systems when exposure time to the very-high temperatures of ballistic gases was brief.

Molybdenum parts can be welded by inertia, resistance, and spot methods in air; by TIG and MIG welding under inert atmospheres; and by electron-beam welding in vacuum. The best welds are produced by inertia (friction) welding and electron-beam welding; welds produced by the other techniques are less ductile. Generally, arc-cast metal develops better welds than do powder-metallurgy products. Heavy sections of molybdenum should be preheated and post heated when they are welded to reduce thermal stresses.

Because molybdenum has a modulus of elasticity of 47x106 psi at room temperature (20°C), it is used for boring bars and the quills for high-speed internal grinders to avoid vibration and chatter. Its relatively high electrical conductivity makes unalloyed molybdenum useful for electrical and electronic applications. It is used in the manufacture of incandescent lamps, as substrates in solid-state electronic devices, as electrodes for EDM equipment and for melting glass, and as heating elements and reflectors or radiation shields for high-temperature vacuum furnaces.

Because it retains usable strength at elevated temperatures, has a low coefficient of thermal expansion, and resists erosion by molten metals, the TZM alloy is used for cores in die casting of aluminium, and for die cavities in casting of brass, bronze, and even stainless steel. Dies of the TZM alloy weighing several thousand pounds are used for isothermal forging of super alloy components for aircraft gas turbines, and die inserts made of TZM have been used for extruding steel shapes. Piercer points of TZM are used to produce stainless-steel seamless tubing.

Tungsten: In many respects, tungsten is similar to molybdenum. The two metals have about the same electrical conductivity and resistivity, coefficient of thermal expansion, and about the same resistance to corrosion by mineral acids. Both have high strength at temperatures above 2,000°F, but because the melting point of tungsten is higher, it retains significant strength at higher temperatures than molybdenum does. The elastic modulus for tungsten is about 25 per cent higher than that of molybdenum and its density is almost twice that of molybdenum. All commercial unalloyed tungsten is produced by powder-metallurgy methods; it is available as rod, wire, plate

sheet, and some forged shapes. For some special applications, vacuum-arc-melted tungsten can be produced, but it is expensive and limited to relatively small sections.

Several tungsten alloys are produced by liquid-phase sintering of compacts of tungsten powder with binders of nickel-copper, iron-nickel, iron-copper, or nickel-cobalt-molybdenum combinations. tungsten usually comprises 85-95 per cent of the alloy by weight. These alloys are often identified as heavy metals or machinable tungsten alloys. In compact forms, the alloys can be machined by turning, drilling, boring, milling, and shaping; they are not available in mill product forms because they are unable to be wrought at any temperature.

The heavy metal alloys are especially useful for aircraft counterbalances and as weights in gyratory compasses. Heavy-metal inserts are used as the cores of high-mass military projectiles. Tungsten alloys are widely used for counterbalances in sports equipment such as golf clubs and tennis racquets. X-ray shielding is another important application of the tungsten alloys.

Filaments for incandescent lamps are usually coils of very fine unalloyed tungsten wire. Electronic tubes are often constructed with tungsten as the heaters; some advanced tubes use heaters made from a tungsten alloy containing 3 per cent rhenium. A thermocouple rated to 4,350°F consists of one tungsten wire alloyed with 25 per cent rhenium and another wire alloyed with 5 per cent rhenium.

Nozzle throats of forged and machined unalloyed tungsten have been used in solid-fuel rocket engines; at one time, throats were machined from porous consolidations of tungsten powder that were infiltrated with silver for exposure to gases at temperatures near 3,500°C. Unalloyed tungsten is used for X-ray targets, for filaments in vacuum-metalizing furnaces, and for electrical contacts such as the distributor points in automotive ignition systems. Tungsten electrodes form the basis for TIG welding. Water-cooled tungsten tips are used for non-consumable electrode vacuum-arc melting of alloys.

Cutting tools and parts that must resist severe abrasion are often made of tungsten carbide. Tungsten-carbide chips or inserts, with the cutting edges ground, are attached to the bodies of steel tools by brazing or by screws. The higher cutting speeds and longer tool life made feasible by the use of tungsten-carbide tools are such that the inserts are discarded after one use.

Tungsten-carbide dies have been used for many years for drawing wire. Inserts of tungsten carbide are used in rotary bits for drilling oil & gas wells and in mining operations. Fused tungsten carbide is applied to the surfaces of mining machinery that is subjected to severe wear.

Titanium

Depending on the predominant phase or phases in their microstructure, titanium alloys are categorized as alpha, alpha-beta, and beta. This natural grouping not only reflects basic titanium production metallurgy, but it also indicates general properties peculiar to each type. The alpha phase in pure titanium is characterized by a hexagonal close-packed crystalline structure



that remains stable from room temperature to approximately 1,620°F. The beta phase in pure titanium has a body-centered cubic structure, and is stable from approximately 1,620°F to the melting point of about 3,040°F.

Adding alloying elements to titanium provides a wide range of physical and mechanical properties. Certain alloying additions, notably aluminium, tend to stabilize the alpha phase; that is, they raise the temperature at which the alloy will be transformed completely to the beta phase. This temperature is known as the beta-transus temperature.

Alloying additions such as chromium, columbium, copper, iron, manganese, molybdenum, tantalum, and vanadium stabilize the beta phase by lowering the temperature of transformation from alpha to beta. Some elements, notably tin and zirconium, behave as neutral solutes in titanium and have little effect on the transformation temperature, acting instead as strengtheners of the alpha phase.

Alpha Alloys: The single-phase and near-single-phase alpha alloys of titanium have good weldability. The generally high aluminium content of this group of alloys ensures good strength characteristics and oxidation resistance at elevated temperatures (in the range of 600 to 1,100°F). Alpha alloys cannot be heat treated to develop higher mechanical properties because they are single-phase alloys.

Alpha-Beta Alloys: The addition of controlled amounts of beta-stabilizing alloying elements causes the beta phase to persist below the beta transus temperature, down to room temperature, resulting in a two-phase system. These two-phase titanium alloys can be strengthened significantly by heat treatment consisting of a quench from some temperature in the alpha-beta range, followed by an aging cycle at a somewhat lower temperature. Beta-phase transformation, which would normally occur on slow cooling, is suppressed by the quenching. The aging cycle causes the precipitation of some fine alpha particles from the metastable beta, imparting a structure that is stronger than the annealed alpha-beta structure. Although heat-treated alpha-beta alloys are stronger than the alpha alloys, their ductility is proportionally lower.

Beta Alloys: The high percentage of beta-stabilizing elements in these alloys results in a microstructure that is substantially beta. The metastable beta can be strengthened considerably by heat treatment.

Titanium is used in corrosive environments or in applications that require light weight, high strength-to-weight ratio, and nonmagnetic properties. While commercially available in many alloys, most requirements can be met by a grade of commercially pure titanium, titanium-0.2% palladium alloy, or by the high-strength Ti-Al-V-Cr (beta type) alloys. These grades, which are available in most common wrought mill forms, are covered by ASTM-AMS specifications and, in most cases, by a similar ASME specification.

Beta-21S is a new beta alloy developed as an oxidation-resistant aerospace material and as a matrix for metal-matrix composites.

Composition is Ti-15Mo-2.7Nb-3Al-0.2Si, with molybdenum and niobium working synergistically to raise corrosion resistance to very high levels. It also offers one of the lowest hydrogen uptake efficiency levels of any titanium alloy. The combination of high strength and high corrosion resistance makes it an ideal candidate for orthopedic implants, deep sour oil wells, and geothermal brine wells.

Like stainless steel, titanium sheet and plate work harden significantly during forming. Minimum bend-radius rules are nearly the same for both, although spring back is greater for titanium. Commercially pure grades of heavy plate are cold formed or, for more severe shapes, warm formed at temperatures to about 800°F. Alloy grades can be formed at temperatures as high as 1,400°F in inert-gas atmospheres. Tube can be cold bent to radii three times the tube OD, provided that both inside and outside surfaces of the bend are in tension at the point of bending. In some cases, tighter bends can be made.

Despite their high strength, some alloys of titanium have super plastic characteristics in the range of 1,500 to 1,700°F. The alloy used for most super plastically formed parts is the standard Ti-6Al-4V alloy. Several aircraft manufacturers are producing components formed by this method. Some applications involve assembly by diffusion bonding.

Titanium plates or sheets can be sheared, punched, or perforated on standard equipment. Titanium and Ti-Pd alloy plates can be sheared, subject to equipment limitations similar to those for stainless steel. The harder alloys are more difficult to shear, so thickness limitations are generally about two-third those for stainless steel.

Titanium and its alloys can be machined and abrasive ground; however, sharp tools and continuous feed are required to prevent work hardening. Tapping is difficult because the metal galls. Coarse threads should be used where possible.

Titanium castings can be produced by investment or graphite-mold methods. Casting must be done in a vacuum furnace, however, because of the highly reactive nature of titanium in the presence of oxygen. Typical applications for titanium castings are surgical implants and hardware for marine and chemical equipment such as compressors and valve bodies.

Generally, titanium is welded by gas-tungsten arc (GTA) or plasma-arc techniques. Metal inert-gas processes can be used under special conditions. Thorough cleaning and shielding are essential because molten titanium reacts with nitrogen, oxygen, and hydrogen, and will dissolve large quantities of these gases, which embrittles the metal. In all other respects, GTA welding of titanium is similar to that of stainless steel. Normally, a sound weld appears bright silver with no discolouration on the surface or along the heat-affected zone.

Zirconium

In addition to resisting HCl at all concentrations and at temperatures above the boiling temperature, zirconium and its alloys also have excellent resistance in sulphuric acid at temperatures above boiling and concentrations to 70 per cent. Corrosion rate in nitric acid is less than 1 mil/year at temperatures above boiling and concentrations to 90 per cent. The metals also resist most organics such as acetic acid and acetic anhydride as well as citric, lactic, tartaric, oxalic, tannic, and chlorinated organic acids.



Relatively few metals besides zirconium can be used in chemical processes requiring alternate contact with strong acids and alkalis. However, zirconium has no resistance to hydrofluoric acid and is rapidly attacked, even at very low concentrations.

Zirconium alloys can be machined by conventional methods, but they have a tendency to gall and work harden during machining. Consequently, tools with higher than normal clearance angles are needed to penetrate previously work-hardened surfaces. Results can be satisfactory, however, with cemented carbide or high-speed steel tools. Carbide tools usually provide better finishes and higher productivity.

Mill products are available in four principal grades: 702, 704, 705, and 706. These metals can be formed, bent, and punched on standard shop equipment with a few modifications and special techniques. Grades 702 (unalloyed) and 704 (Zr-Sn-Cr-Fe alloy) sheet and strip can be bent on conventional press-brake or roll

forming equipment to a 5t bend radius at room temperature and to 3t at 200°C. Grades 705 and 706 (Zr-Cb alloys) can be bent to a 3t and 2.5t radius at room temperature and to about 1.5t at 200°C.

Zirconium has better weldability than some of the more common construction metals including some alloy steels and aluminium alloys. Low distortion during welding stems from a low coefficient of thermal expansion. Zirconium is most commonly welded by the gas-tungsten arc (GTAW) method, but other methods can also be used, including gas metal-arc (GMAW), plasma-arc, electron-beam, and resistance welding.

Welding zirconium requires proper shielding because of the metal's reactivity to gases at welding temperatures. Welding without proper shielding (argon or helium) causes absorption of oxygen, hydrogen, and nitrogen from the atmosphere, resulting in brittle welds. Although a clean, bright weld results from the use of a proper shielding system, discolouration of a weld is not necessarily an indication of its unacceptability. However, white deposits or a black colour in the weld area are not acceptable. A bend test is usually the best way to determine acceptability of a zirconium weld.

Major uses for zirconium and its alloys are as a construction material in the chemical-processing industry. Applications include heat exchangers (for producing hydrogen peroxide, rayon, etc.), drying columns, pipe & fittings, pump & valve housings, and reactor vessels.

Summary & Conclusion

Non-ferrous metals such as copper, brasses, bronzes, aluminium, magnesium, nickel, chromium, titanium, lead, tin, zinc, gold, silver, platinum, the refractory metals, and their alloys are used in a wide variety of applications; each requiring specific characteristics. Metals such as aluminium and magnesium, for example, tend to be high-strength, lightweight, and corrosion-resistant. They offer advantages over other metals in applications which depend on their unique properties. Refractory metals are chosen for their high heat resistance. They retain their properties at elevated temperatures. The precious metals are chosen for their luster in applications such as coinage and jewelry. Additionally, they may be used in electrical conductors, contacts, and biocompatible applications.

Some of these metals are chosen to plate other metals such as nickel, chromium, and zinc which are used to provide a resistant outer shell. Copper is an excellent conductor and used in applications which require high conductivity. Its alloys, brasses and bronzes, are typically alloyed for specific purposes.

Aluminium is the third most abundant element in the earth's crust, behind silicon and oxygen. It is the most abundant metal. Aluminium is strong, lightweight, electrically- and thermally-conductive, and corrosion resistant. These properties can be enhanced through alloying. It is often anodized to help prevent corrosion.

Its electrical conductivity makes it an excellent choice for electrical applications such as wiring and conductors. Its strength-to-weight ratio makes it attractive in structural applications as well as cast aluminium engine components, e.g. blocks, heads, and manifolds. Its high reflectivity of infrared and visible radiation makes it desirable in headlights, light fixtures, and many insulations. It is also used as a paint pigment.

Copper has been used in various applications for centuries. It generally finds applications requiring high thermal and electrical conductivity. For example, the thermal conductivity of copper is almost ten times greater than ordinary steel. Therefore, it finds use as kitchen products, wiring & electrical applications, piping & tubing, and other such uses.

Alloys of copper and zinc are termed brasses. Zinc is added to improve the strength and ductility of the alloy. There are many formulas for brasses which include other alloying elements than copper and zinc. Brass is used in decorative metal products, cartridge cases, piping and tubing, and many of the same application as copper.

Bronze is an alloy of copper and any other metal. As with brasses, there are many formulas for bronzes, depending on the application. Aluminium bronzes, tin bronzes, phosphor bronzes, nickel bronzes, and silicon bronzes are all examples of varying alloys. The principal alloying element determines the nomenclature. Bronzes are used in applications such as bearings, some limited structural applications, decorative uses, and applications which require them not to spark when struck with another metal. This makes them useful in the transport and handling of items such as explosives, fuels, and flammable materials. Bronzes are often used in statues and can be seen to form the familiar green oxidized coating.

Magnesium is a light material, lighter than aluminium, derived primarily from seawater. Magnesium is a very active metal and, when burned, gives off an intense heat and light. It is used as an alloying element in steels and in applications which require high strength-to-weight ratios, such as extension ladders, aircraft, space vehicles, power tools, and similar applications.

Chromium is often used in decorative and corrosion-resistant coatings. It is a major alloying element in many steels, especially stainless steels. It is used to provide a tough, wear-resistant, corrosion-resistant, decorative surface.

Nickel is used as a plating material. It polishes to a high luster. It offers a wide working temperature range. It is also used as an alloying element for other materials, such as steels and bronzes. Nickel is also used in magnets, heating elements, thermocouples, and rechargeable batteries. Nickel and nickel silver are used in jewelry and coins.

Gold, Silver & Platinum are generally termed the precious metals due to their cost/value and use in coinage and jewelry. For example, the $20 gold piece at one time contained $20 worth of gold. Today, coins are used to represent the face value and are made from less expensive materials. Gold, silver, and platinum are used as plating materials. They offer good conductivity and

corrosion resistance. Gold and silver are too soft to be used in a pure form and are often alloyed with copper, nickel, or platinum to increase their strength. Gold and silver have been used for dental caps, crowns, and fillings.

Silver also finds application in photographic films and papers. At one time, it was used to plate mirrors. It is now used in the manufacture of photo chromatic lenses. Photo chromatic lenses darken when exposed to ultraviolet light. Silver is also used in brazing alloys and long-life batteries. Silver fulminate ($Ag_2C_2N_2O_2$) is used as an explosive. Silver and silver compounds are found in many creams, ointments, and salves used for medicinal purposes. Silver iodide has been used to seed clouds to make rain.

Platinum is found in a group of six metals extracted from nickel ores - iridium, osmium, palladium, rhodium, ruthenium, and platinum. Of these, platinum has the most widespread application. It is used in corrosion-resistant coatings, as a catalyst for chemical reactions, high-resistance furnace wire, and in catalytic converters. A large percentage of platinum is used in laboratory equipment, medical instruments, and fine jewelry. Platinum is more expensive per pound than gold.

Refractory metals have melting temperatures above 3600 degrees Fahrenheit (2000 degrees Celsius). Some of these approach 6200 degrees Fahrenheit (3500 degrees Celsius). They include such metals as iridium, osmium and ruthenium, in addition to chromium, columbium, hafnium, molybdenum, niobium, rhenium, tantalum, tungsten, and vanadium. They find application where high temperature stability is required. For example, furnace components, high speed tools, temperature-measuring devices and components, aircraft components and space vehicle shields. These metals also find application in electrical devices such as capacitors and rectifiers.

Titanium is lightweight and strong. It is an important metal for the aerospace industry which requires high strength under extreme conditions. It is also used in the medical field for instruments and artificial joint replacements. Titanium is also used as a pigment in paints.

White metals include antimony, bismuth, cadmium, lead, tin, and zinc. Of these, lead, tin, and zinc are of primary interest.

Lead has been used for centuries for plumbing and plumbing-related uses, such as solders, pipe, and fittings. It is easily formed with low heat, corrosion resistant, and ductile. One primary use of lead in the past was as a pigment in lead-based paints. Another prior use for lead was as an octane booster in gasoline as tetraethyl lead. Modern paints and fuels do not contain lead. Lead has been identified as a health hazard and found to be toxic to animals and humans. Lead is used in storage batteries where the battery plates contain high percentages of lead. Due to its high density, it is also used as radiation shielding

Tin is a major component of solders and pewter. It is also used as both an alloying element and plating material. Tin is a major alloy of many copper products. It is used to plate other metals due to its corrosion resistance.

Zinc is commonly used as a plating material for steels. This product is termed galvanized steel. It is the familiar grayish coating seen on products such as nails and sheets. It is also used in die castings (such as die-cast children's toys, carburetor bodies, and pump housings) and as an alloying element in non-ferrous metals. Zinc oxide is used in paints, glass, cements, and medicines.

Finally, antimony, bismuth, and cadmium are included in "white" metals. Antimony is used in solders and as an alloying element in non-ferrous metals. The same may be said for bismuth which has the lowest thermal conductivity of any metal except mercury. Cadmium is used as a plating material, as a component of rechargeable batteries (Nickel-cadmium batteries), and as a neutron absorber in control rods for nuclear power plants. Zirconium is also used in nuclear reactor structures and fuel shielding due to its low neutron absorption.

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CHAPATER 6

Development of Titanium Based Industries

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RECOVERY OF TITANIUM OXIDE FROM UNDIGESTED SAND OF AN INDIAN ALUMINA REFINERY AND PREPARATION OF VALUE ADDED TITANIUM CARBIDE

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Keywords: Bauxite, Alumina, Undigested Sand, Plasma processing, Titanium Carbide

Abstract

During the process of alumina production through Bayer's process, around 60% of unwanted gangue is rejected as 'undigested sand' and 'Red Mud'. This industrial waste material poses environmental and disposal problems. Aluminum oxide constitutes only 38 to 60% of bauxite ore. The rest is made up of Fe_2O_3, SiO_2, TiO_2 and some other metallic oxides. After dissolution of alumina in caustic soda, these impurities remain in suspended form which is separated out as undigested sand and subsequently as red mud. Out of these metal oxides, around 8 to 25% of titanium oxide is lost in to this waste. Titanium oxide, present as rutile and ilmenite in the undigested sand, was processed through Wilfley table. A concentrate containing 38% TiO_2 with 47.30% recovery was obtained. This concentrate was subjected to smelting with activated carbon in an extended arc plasma reactor. Titanium carbide was formed as a fused mass within 5 minutes.

Introductinn

Around 3 MT of bauxite ore is processed in the alumina refinery employing the time tested Bayer's process, to produce approximately 1 MT of alumina. During the process of alumina production about 60% of unwanted gangue is rejected as 'undigested sand' and 'Red Mud'. Out of total quantity of 200-300 Million tonne per year (Mtpy) of red mud generated in the world, India accounts for about 2Mtpy. This industrial waste material poses tremendous environmental and disposal problems. With the anticipated expansion of alumina Industry in the country, Indian alumina plants have to very soon dispose off over 6 Mt of this red mud every year.

Aluminium oxide from which aluminium metal is extracted, constitutes only 38 to 60% of bauxite ore. The rest is made up of Fe_2O_3, SiO_2, TiO_2 and several other metallic oxides. After dissolution of alumina in caustic soda, these impurities remain in suspended form which is separated out after being washed and then pumped as slurry to the nearby Red Mud pond. During Bayer's process, all alumina content present in bauxite is not recovered and appreciable quantity of alumina goes into the red mud along with other valuable metals. Though some studies have been undertaken by other researchers to recover metal values from red mud, they are not considered economically viable. However, the undigested sand that constitutes around 20% of the refinery rejects is reported to contain between 8-25% TiO_2 and some other metal values which may be recovered in view of their scarcity and [illegible]

This paper describes the detailed beneficiation technique adopted to recover Titanium value from undigested sand and discusses the processing of Titanium oxide pre-concentrate to smelting in an extended arc plasma reactor for production of value added Titanium carbide.

Materials and Methods

Representative undigested sand sample was collected from an Indian alumina refinery. For processing of undigested sand, around 5 kg (unclassified) of the material was directly treated on the Wilfley Table at different angles. The effect of particle size, classification, wash water, deck length etc. on the Wilfley table was studied during the table operation. Another 10 kg of the same sample was further classified at 100 microns. The operational conditions for tabling of −100 micron fraction were same as the unclassified sample. The operating parameters for tabling of -100 microns fraction on slime table were 10mm stroke length, 1-degree angle and 4 liters per minute of wash water.

Mineralogical analysis was undertaken by Philips XRD and Leitz optical microscope. The micro-chemical composition of feed and processed product was determined by Jeol make Electron Probe Micro Analyser [EPMA, JXA-8100]

The beneficiated Ti-rich concentrate was subjected to plasma smelting with appropriate amount of activated carbon. Before plasma treatment, the concentrate was finely ground and mixed with activated carbon thoroughly for better interaction. Finally, the mixture was pelletized using Poly Vinyl Alcohol as the binder and dried. The plasma treatment was taken up in an indigenously designed 50 kW DC pot type extended arc thermal plasma reactor. The plasma reactor essentially consists of: (i) a top graphite electrode through which the argon gas is introduced to the reactor through the axial holes in the top electrode (ii) a graphite crucible, which forms the bottom electrode

Results and Discussion

Mineralogy

Megascopically, the undigested sand sample is black to brick red in colour. In view of its appearance [illegible] sand sized grains, the sample is termed as undigested sand or plant sand. The constituents of undigested sand [illegible] phases. The mineral [illegible] sample [illegible]

scanning electron microscopes are ilmenite and zircon along with rare sillimanite, mica, goethite and kaolinite booklets. Rutile appears either needle like or platy while ilmenite exhibits a sub-hedral form. Both these crystals exhibit twinning and generally occur in free independent state.

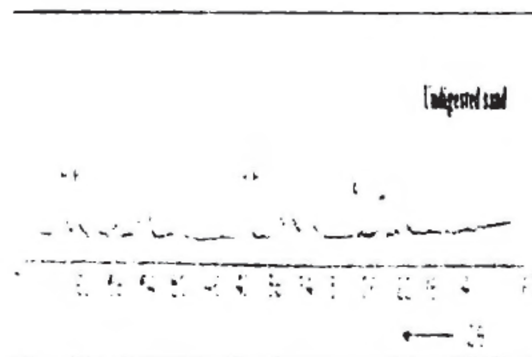


Fig.1. X-ray diffraction patterns of bulk undigested sand [Go: Goethite, H: Hematite; R: Rutile]

Predominance of rutile in -300+100micron size fraction is evident from XRD pattern. As ilmenite in the sample is present in minor amount, no reflection peak appears in XRD pattern. However, presence of both these phases is clearly indicated from their compositional map (Fig.2).

Physical Beneficiation

The bulk feed sample when processed through a Table, a product containing 38.87% TiO_2 with 47.23% recovery was obtained at a deck angle of 3 degrees. Since the sample contains very less amount of finer particles, it was possible to get a good grade material at a deck angle of 1.5 degrees, wash water rate of 2.5 to 3 liters per minute and a stroke length of 10 mm. Table 1 shows the typical result obtained by beneficiating the undigested sand sample using Wilfley table.

Table 1: Tabling studies results (in %) of undigested sand (Deck angle 1.5 degree, % solid 10, wash water 2.5 ltr/min.)

Details	Wt %	TiO_2 %	Fe_2O_3 %	Al_2O_3 %	SiO_2 %	% of TiO_2 Recovery
Heavies	12.54	38.87	56.98	2.45	0.99	47.23
Middling	42.90	8.11	74.75	8.04	1.21	33.90
Tailing	44.56	4.30	71.42	11.93	2.85	18.80
Head	100	10.27	71.04	9.07	1.91	-

In case of classified -100 micron fractions [18.46 wt%] a high weight percent of rougher concentrate was collected followed by cleaning the same to obtain a cleaner concentrate assaying 37.30% TiO_2 having 53.96% Fe_2O_3 with a recovery of 25.79% weight percent. However, in case of +100 micron fractions [81.54 wt%] a concentrate analyzing 41.75% TiO_2 and 53.70% Fe_2O_3 in 29.68% weight recovery was obtained (Table-2). This operation removed not only the associated [illegible] mineral but also the coating of [illegible]

Table 2: Tabling studies of size classified results (in %) of undigested sand

Size, in µ	Wt %	Details	Wt% w.r.t feed	TiO_2 %	Fe_2O_3 %	Al_2O_3 %	SiO_2 %	% of TiO_2 Recovery
+100	81.54	Heavies	7.30	41.75	53.70	3.28	2.49	29.68
		Middlings1	1.56	20.88	69.84	7.52	0.60	3.08
		Middlings2	21.00	2.53	1.84	6.91	1.32	22.00
		Lights	51.74	8.18	67.60	17.10	29.00	18.10
-100	18.46	Heavies	7.10	37.30	53.96	3.10	0.94	25.79
		Middling1	2.30	20.65	69.01	5.38	2.16	4.62
		Middling2	6.40	8.2[illegible]	78.08	8.47	1.66	4.44
		Lights	2.66	8.16	74.02	10.20	1.60	1.20

A high weight percent of rough concentrate was obtained by increasing the deck angle. No significant improvement with respect to titania grade was achieved by cleaning the rougher concentrate and tailings. Similarly, increasing the collection length marked no improvement. Table 3 shows the summary of grade and TiO_2% recovery of Tabling study.

Table 3: Summary of the tabling studies on TiO_2 recovery

		Weight%	Grade%	Recovery %
As received sample		12.48	38.87	47.23
Two step	01	14.40	39.55	55.47
Classification technique	02	18.20	35.62	63.13

The light fraction (tailings) is mostly enriched in hematite, goethite and quartz. The magnitude of XRD peak diagnostic of rutile increases in heavy fraction (concentrate) as compared to the bulk feed sample (Fig.3). The unrecovered Ti values (4 to 5%) in the tailings was due to the presence of some minute ilmenite flakes and rutile needles which got escaped during tabling operation eventually due to their typical morphology.

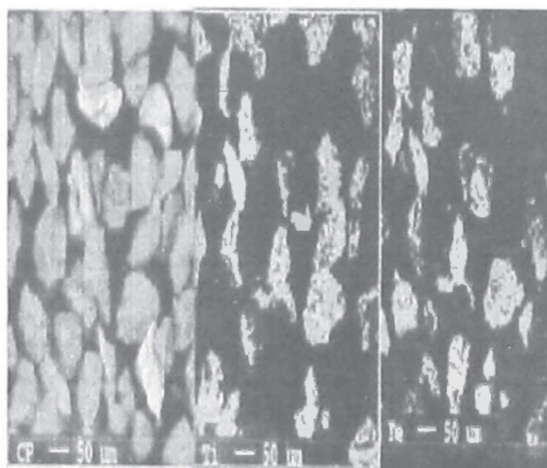


Fig.2: Compositional map of beneficiated plant sand showing Ti- [illegible]

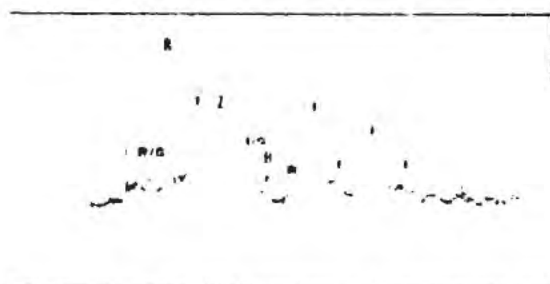


Fig. 3: XRD pattern of Beneficiated Plant Sand
[R: Rutile; S: Silimanite; I: Ilmenite; Z: Zircon; H: Hematite]

Titanium Carbide Preparation

The oven dried Ti-rich pellets were directly charged into graphite hearth of the extended hearth plasma reactor. The plasma processed product was obtained in the form of fused mass and some powder. The polished surface of fused mass show small grains of Ti-C distributed within a homogenous Fe-rich matrix. Theses grains are generally globular in shape, vary in size between 5 and 30 microns, pink in colour and show relatively high relief. X-ray diffraction pattern (Fig.4) and compositional maps (Fig.5) confirm both titanium and Fe-rich phase.

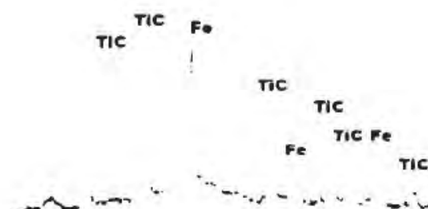


Fig. 4: XRD pattern of Plasma Processed Sample
[TiC: Titanium Carbide; Fe: Iron]

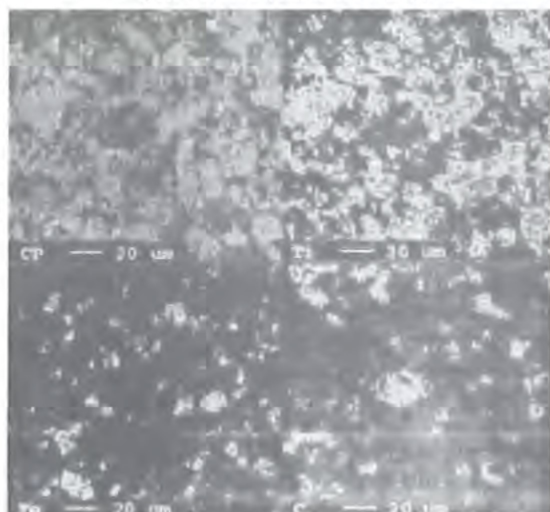


Fig.5: [illegible]

The fused mass was ground in the HERZOG Swing Mill Grinder HSM 100 for 5 minutes. The fine powder was then subjected to acid leaching to liberate TiC. The acid leaching has been found effective in removing the Fe from TiC as seen in its XRD pattern (Fig.6) and compositional map (Fig.7). However, the additional carbon shown in XRD can be removed through heavy media separation. The TiC thus produced from undigested sand matches well with the XRD pattern of commercial product.

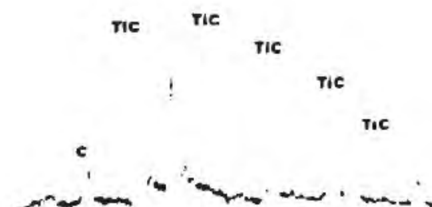


Fig.6: XRD pattern of Acid Leached Sample
[TiC: Titanium Carbide; C: carbon]

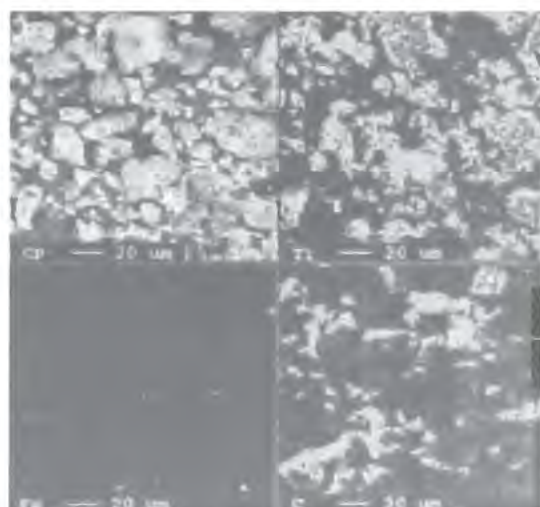


Fig.7: Compositional map of acid leach sample showing Ti, Fe and C.

Conclusions

The undigested sand from an alumina refinery plant contains significant titanium oxide (TiO_2 10%) value, contributed by rutile and ilmenite. The mineral responsible for this significant value do appear in free and independent state. Studies were carried out by gravity separation technique (using Wilfly Table) to recover the Titanium oxide mineral. A concentrate containing 38.87% of TiO_2 with 47.23% recovery was obtained. However, the grade improves in coarser fraction when the bulk sample is classified. The titanium rich concentrate, so obtained through beneficiation, was subjected to plasma smelting with appropriate [illegible] activated carbon so as to convert [illegible] titanium carbide (Fe-TiC). [illegible]

Acknowledgement

The authors are thankful to the Director, CSIR-Institute of Minerals and Materials Technology, Bhubaneswar for permitting to publish this paper.

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Preparation of Titanium Carbide from Titanium Oxide recovered from Undigested Sand of an Indian Alumina Refinery through physical beneficiation

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ABSTRACT

Alumina is produced from khondalite hosted bauxite of Indian origin in the Alumina refinery employing the time tested Bayer's Process. When 2.4 MT of bauxite per annum is processed in a refinery, it produces approximately 0.8 MT of alumina. During the process of alumina production, about 60% of unwanted gangue is rejected as 'undigested sand' and 'Red Mud'. Out of total quantity of 70 Million tonnes per year (Mtpy) of red mud in the world, India accounts for about 2 Mtpy. This industrial waste material poses tremendous environmental and disposal problems. With the anticipated expansion of alumina Industry in the country, Indian alumina plants have to dispose of over 5 Mt of this red mud every year. Aluminium Oxide constitutes 38 to 60% of bauxite ore. The rest is made up of Fe_2O_3, SiO_2, TiO_2 and other metallic oxides. After dissolution of alumina in caustic soda, these impurities remain in suspended form which is separated out as undigested sand and subsequently as red mud. Out of these metal oxides, around 8 to 25% of Titanium Oxide is lost in to this waste. Titanium Oxide is invariably present as rutile and ilmenite in the undigested sand. This Titanium Oxide phases were processed through cost effective beneficiation technique. A concentrate containing 38% TiO_2 with 47.30% recovery was obtained.

This paper while enlisting the extent of various metal values disposed as rejects (undigested sand and red mud), describes the detailed beneficiation technique to recover Titanium value from undigested sand and discusses the processing of Ti-rich concentrate to smelting with activated carbon in an extended arc plasma reactor and production of Fe-TiC composite as a fused mass within 5 minutes. After grinding and leaching, TiC powder was obtained and it was found to be comparable with the commercial grade Titanium Carbide.

Key words: Bauxite, Alumina Refinery Rejects, Undigested Sand, TiO_2 -Beneficiation, TiC

1.0 INTRODUCTION

In an alumina refinery, around 3 MT of bauxite ore is processed to produce approximately 1 MT of alumina employing the time tested Bayer's process. During the process of alumina production about 60% of unwanted gangue is rejected as 'undigested sand' and 'Red Mud'. India accounts for about 2 Million tonne per year (Mtpy) of red mud out of total quantity of 200-300 Mtpy generated in the world. This industrial waste material poses tremendous environmental and disposal problems. Indian alumina plants have to very soon dispose off over 6 Mt of this red mud every year due to its expansion programme.

In a bauxite ore, aluminium oxide, from which aluminium metal is extracted, constitutes only 38 to 60%. Other phases are Fe_2O_3, SiO_2, TiO_2 and some other metallic oxides. After dissolution of alumina in caustic soda, these impurities remain in suspended form which is separated out after being washed and then pumped as slurry to the nearby Red Mud pond. All alumina content present in bauxite is not recovered during Bayer's process and appreciable quantity of alumina goes into the red mud along with other valuable metals. Attempts have been made by others to recover metal values from red mud but they are not considered economically viable. However, the undigested sand that constitutes around 20% of the refinery rejects is reported to contain between 8-25% TiO_2 and some other metal values which may be recovered in view of their scarcity and significance and processed for value addition. Rao et al [1] have reported the characteristics of undigested sand rejects from the Nalco refinery, Damanjodi, Odisha, India. Limited attempts have been made by some researchers on the characterisation of red mud sludge from this refinery [2-5].

This paper describes the physical beneficiation methods adoptedfor recovery of Titanium Oxide from undigested sand of an Indian Alumina Refinery and discusses the processing of Titanium oxide pre-concentrate to smelting in an extended arc plasma reactor for preparation of Titanium Carbide.

2.0 MATERIALS AND METHODS

Around 15 kg of representative undigested sand sample was collected from an Indian alumina refinery. Half of the sample was directly treated on the Wilfley Table at different angles. The effect of particle size, classification, wash water, deck length etc. on the Wilfley table was studied during the table operation. Other half of the sample was classified at 100 microns. The operational conditions for tabling of +100 micron fraction were same as the unclassified sample. The operating parameters for tabling of -100 microns fraction on slime table were 10mm stroke length, 1-degree angle and 4 liters per minute of wash water.

Philips XRD and Leitz optical microscope were used to identify the mineral species. The micro-chemical composition of feed and processed product was determined by Jeol make Electron Probe Micro Analyser [EPMA, JXA-8100].

The processed Ti-rich concentrate was subjected to plasma smelting with appropriate amount of activated carbon. Before plasma treatment, the concentrate was finely ground and mixed with activated carbon thoroughly for better interaction. Finally, the mixture was pelletized using Poly Vinyl Alcohol as the binder and dried. The plasma treatment was taken up in an indigenously designed 50 kW DC pot type extended arc thermal plasma reactor consisting of: (i) a top graphite electrode through which the argon gas is introduced to the reactor through the axial holes in the top electrode (ii) a graphite crucible, which forms the bottom electrode.

3.0 RESULTS AND DISCUSSION

3.1 Mineralogy

The undigested sand sample is black to brick red in colour. The sample is termed as undigested sand or plant sand in view of its appearance like sand sized grains. Alumina, iron and Ti-rich

phases are the major constituents of undigested sand. Approximately 14 volume % of Ti-phase is present in the present undigested sand. XRD pattern shown in Fig. 1 reveals the undigested sand to be composed predominantly of hematite, rutile and goethite. Hematite and goethite are distributed in all size ranges. Other minor minerals recognized under reflected light microscope and scanning electron microscopes are ilmenite and zircon along with rare sillimanite, mica, goethite, gibbsite and kaolinite booklets. Rutile appears either needle like or platy while ilmenite exhibits a subhedral form. Both these minerals occur in free independent state.

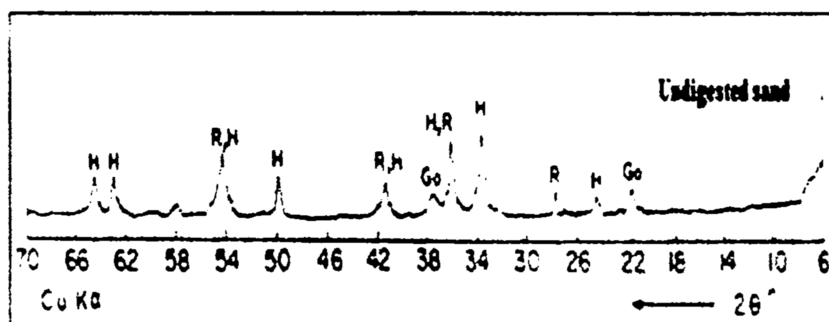


Fig.1: X-ray diffraction patterns of bulk undigested sand
[Go: Goethite; H: Hematite; R: Rutile]

Predominance of rutile in -300+100miron size fraction is evident from XRD pattern. As ilmenite in the sample is present in minor amount, no reflection peak appears in XRD pattern. However, presence of both these phases is clearly indicated from their compositional map (Fig.3).

3.2 Physical Beneficiation

When the bulk sample was processed through a Table, a product containing 38.87% TiO_2 with 47.23% recovery was obtained at a deck angle of 3 degrees. It was possible to get a good grade material at a deck angle of 1.5 degrees, wash water rate of 2.5 to 3 liters per minute and a stroke length of 10 mm as the sample contains very less amount of finer particles. Table 1 shows the typical result obtained by beneficiating the undigested sand sample using Wilfley table.

Table 1: Tabling studies results (in %) of undigested sand
(Deck angle 1.5 degree, % solid 10, wash water 2.5 ltr/min.)

Details	Wt %	TiO_2 %	Fe_2O_3 %	Al_2O_3 %	SiO_2 %	TiO_2 Recovery (%)
Heavies	12.54	38.87	56.98	2.45	0.99	47.23
Middling	42.90	8.11	74.75	8.04	1.21	33.90
Tailing	44.56	4.30	71.42	11.93	2.85	18.80
Head	100	10.27	71.04	9.07	1.91	-

In case of +100 micron fractions [81.54 wt%] a concentrate analyzing 41.75% TiO_2 and 53.70% Fe_2O_3 in 29.68% weight recovery was obtained (Table-2). However, in case of classified -100 micron fractions [18.46 wt%] a high weight percent of rougher concentrate was collected followed by cleaning the same to obtain a cleaner concentrate assaying [illegible] TiO_2 having 53.96% Fe_2O_3

with a recovery of 25.79% weight percent. This operation removed both associated iron mineral and coating of alumina on the surfaces of the intermediates and fines. The performance in this route is much superior to that of any other conventional beneficiation techniques. A high weight percent of rough concentrate was obtained by increasing the deck angle. No significant improvement with respect to titania grade was achieved by cleaning the rougher concentrate and tailings. Similarly, increasing the collection length marked no improvement

Table tailing mostly constitute hematite, goethite and quartz. The magnitude of XRD peak diagnostic of rutile increases in the concentrate as compared to the bulk feed sample (Fig.2). The unrecovered Ti values (4 to 5%) in the tailings was due to the presence of some minute ilmenite flakes and rutile needles which got escaped during tabling operation eventually due to their typical morphology.

Table 2: Tabling studies of size classified results (in %) of undigested sand

Size, in µ	Wt %	Details	Wt% w. r. t feed	TiO_2%	Fe_2O_3%	Al_2O_3%	SiO_2%	TiO_2 Recovery (%)
+100	81.54	Heavies	7.30	41.75	53.70	3.28	2.49	29.68
		Middling1	1.50	20.88	69.84	7.52	0.60	3.05
		Middling2	21.00	12.53	71.84	6.91	1.32	22.00
		Lights	51.74	4.18	67.66	17.10	29.00	18.10
-100	18.46	Heavies	7.10	37.30	53.96	3.10	0.94	25.79
		Middling1	2.30	20.63	69.01	5.38	2.16	4.62
		Middling2	6.40	8.27	78.08	8.47	1.66	4.44
		Lights	2.66	5.16	74.02	10.20	1.60	1.20

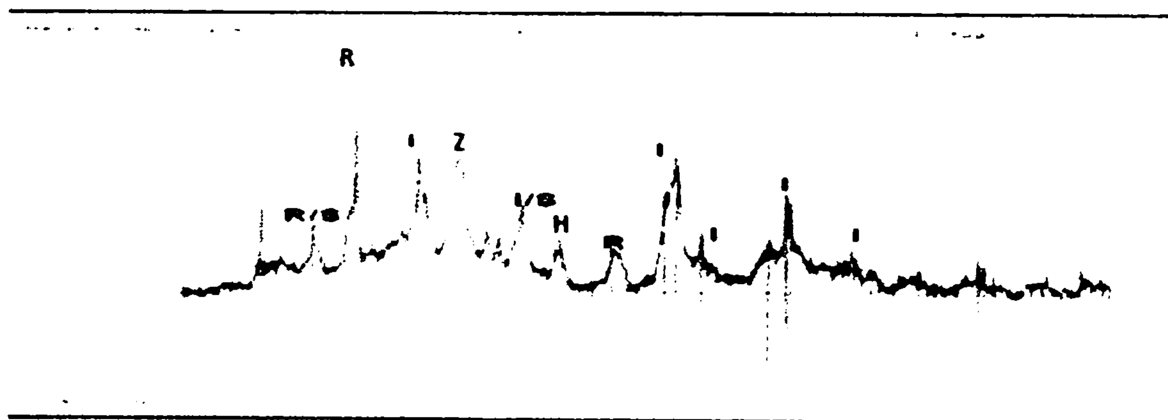


Fig. 2: XRD pattern of Beneficiated Plant Sand
[R: Rutile; S: Silimanite; I: Ilmenite; Z: Zircon; H: Hematite]

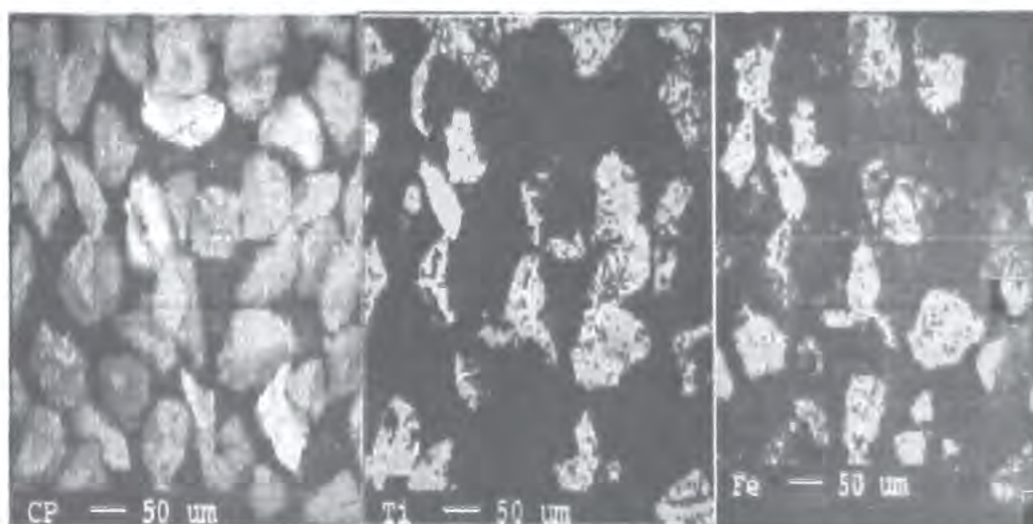


Fig. 3: Compositional map of beneficiated plant sand showing Ti-rich minerals

4.0 PREPARATION OF TITANIUM CARBIDE

The oven dried Ti-rich pellets were directly charged into graphite hearth of the extended hearth plasma reactor. The plasma processed product was obtained in the form of fused mass and some powder. The polished surface of fused mass show small grains of Ti-C distributed within a homogenous Fe-rich matrix. Theses grains are generally globular in shape, vary in size between 5 and 30 microns, pink in colour and show relatively high relief. X-ray diffraction pattern (Fig.4) and compositional maps (Fig.5) confirm both titanium and Fe-rich phase.

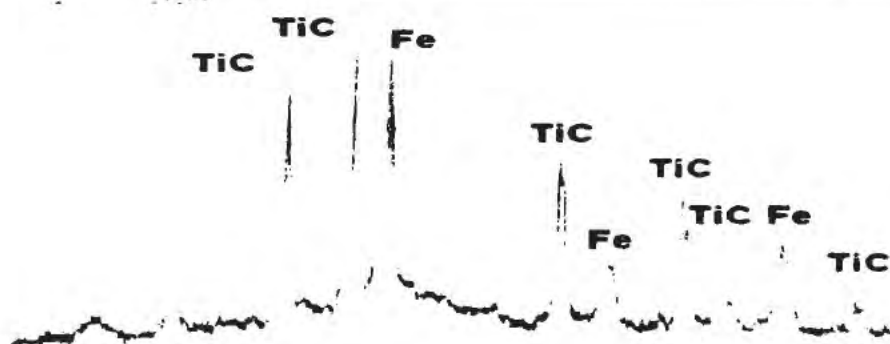


Fig. 4: XRD pattern of Plasma Processed Sample
[TiC: Titanium Carbide: Fe: Iron]

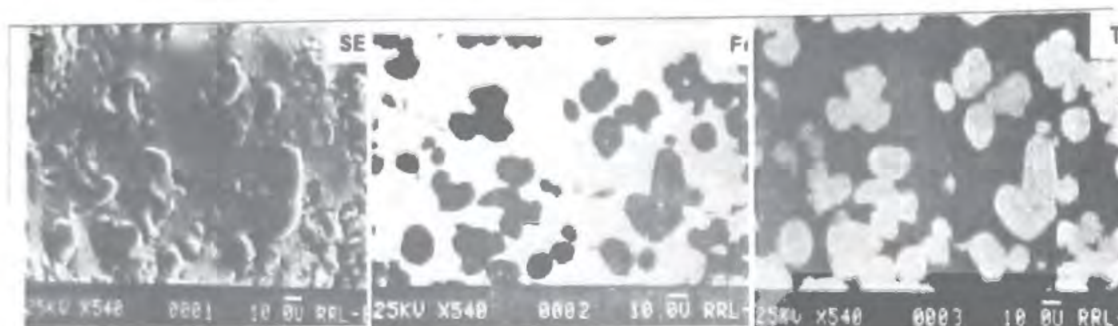


Fig.5: Compositional map of plasma processed sample showing Ti, Fe and C.

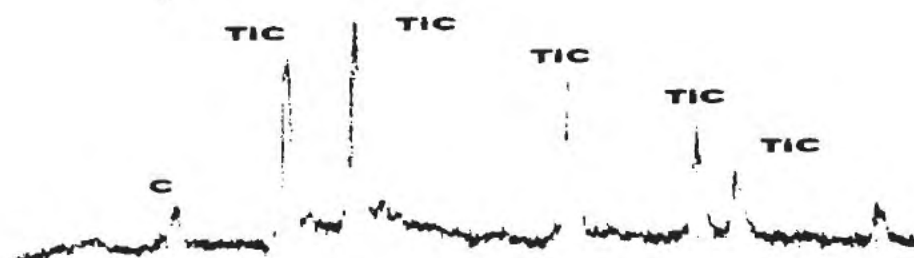


Fig.6: XRD pattern of Acid Leached Sample
[TiC: Titanium Carbide; C: carbon]

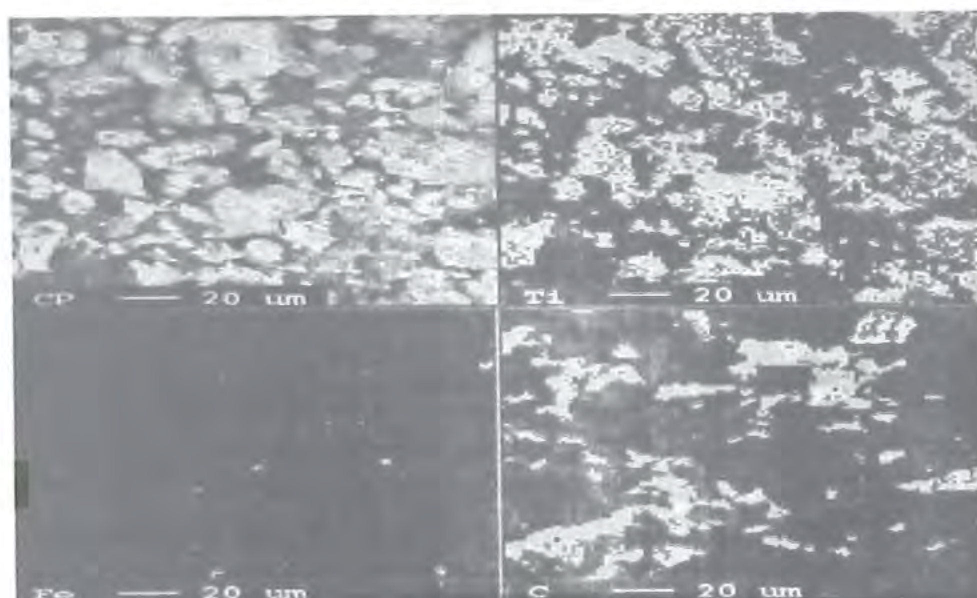


Fig. 7: Compositional map of acid leach sample showing Ti, Fe and C.

The fused mass was ground in the HERZOG Swing Mill Grinder HSM 100 for 5 minutes. The fine powder was then subjected to acid leaching to liberate TiC. The acid leaching has been found effective in removing the Fe from TiC as seen in its XRD pattern (Fig.6) and compositional map (Fig.7). However, the additional carbon shown in XRD can be removed through heavy media separation. The TiC thus produced from undigested sand matches well with the XRD pattern of commercial product.

5.0 CONCLUSIONS

The undigested sand from an Indian alumina refinery plant contains significant titanium oxide (TiO_2: 10%) value, contributed by rutile and ilmenite. These minerals appear in free and independent state. The titanium oxide minerals were recovered by gravity separation technique (using Wiffly Table). A concentrate containing 38.87% of TiO_2 with 47.23% recovery was obtained. However, the grade improves in coarser fraction when the bulk sample is classified. The titanium rich concentrate, so obtained through beneficiation, was subjected to plasma smelting with appropriate amount of activated carbon so as to convert it into a fuse mass of Fe- rich titanium carbide (Fe-TiC). Pure TIC was obtained by grinding the mass followed by acid leaching, which matches well with the commercial product.

6.0 ACKNOWLEDGEMENT

The authors are thankful to the Director, CSIR-Institute of Minerals and Materials Technology, Bhubaneswar for permitting to publish this paper.

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- *Source: IBAAS-CHALIECO, 2013 International Conference held at Nanning, Guangxi, China, Technical Proceedings, pp131-137.*

CHAPATER 7

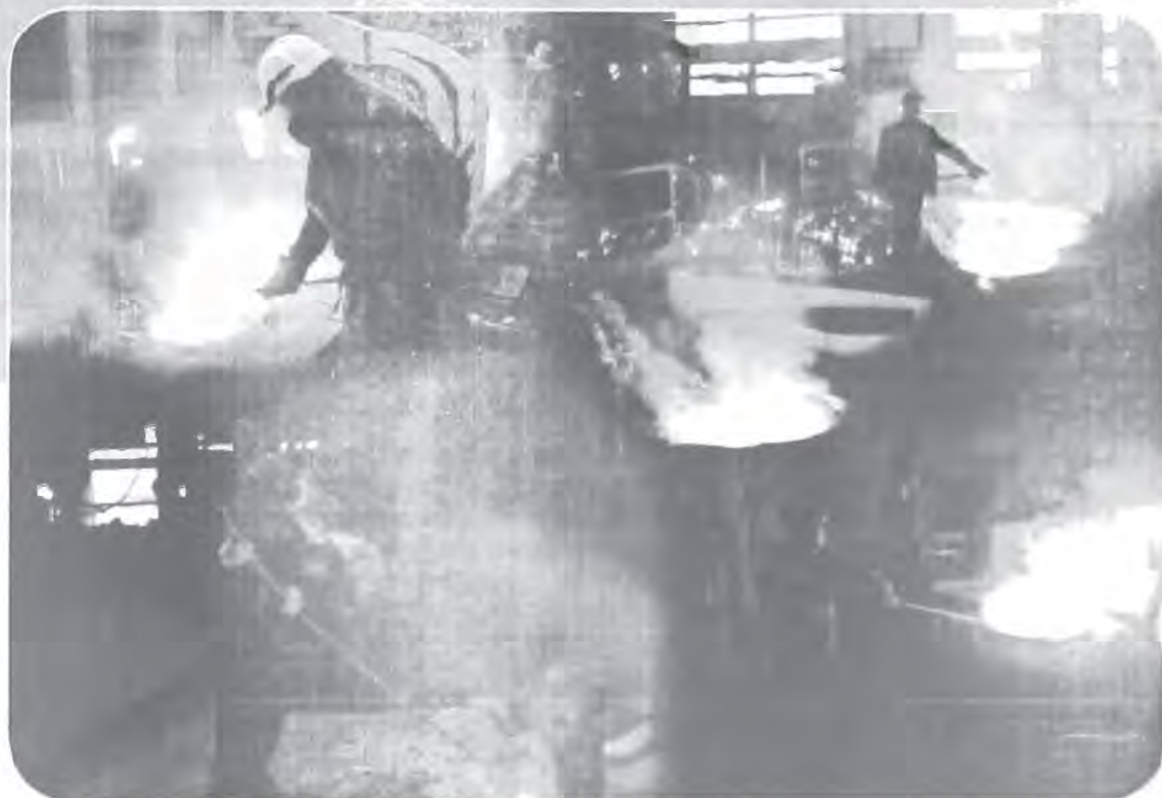
Waste to Wealth

METAL ASIA



Safety, Health & Environmental Issues in the Aluminium Industry

Safety, Health & Environmental Issues in the Aluminium Industry



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Aluminium, the most abundant metal in the earth's crust (making up approximately 8%), has a multitude of uses ranging from aerospace to construction through manufacturing to food and pharmaceutical applications. The production of primary aluminium begins with the mining of bauxite ore and is followed by refining of bauxite to alumina employing the time tested Bayer's Process followed by smelting of alumina to aluminium by the famous Hall-Heroult Process of Electrolysis. The basic chemical process produces, for every 6 kg of bauxite, approximately 2 kg of alumina, 4 kg of hazardous waste material red mud and 1 kg of aluminium metal. Caustic soda is the major raw material used in the alumina refining process. Other raw materials used in the aluminium smelting process include carbon, aluminium fluoride, cryolite, and electrical energy. The chemical, physical, biological, psychosocial, and ergonomic hazards related to primary aluminium production are also characterized, in the context of both occupational and community health. Epidemiological analyses detailing known health risks are comprehensively summarized. Safety, community health and associated environmental issues in relation to alumina & aluminium production facilities, are also discussed.

Bauxite Mining Process and Associated Occupational Health Hazards and Risks

Although a very small percentage (less than 1% globally) of aluminium is obtained from ores such as nepheline and from alternative sources, such as fly ash from coal-fired power stations, bauxite mining represents, by far, the most common initial upstream step in the eventual production of aluminium metal.

Bauxite ore, named for the town of Les Baux, France, is one of the earliest sources of bauxite and contains alumina (Al_2O_3), the immediate precursor of aluminium (Al) in the production cascade. The overwhelming majority of known global bauxite reserves is found in the geographic band bounded by the Tropics of Cancer and Capricorn. Key deposits are found in West Africa, South America and the Caribbean, South and Southeast Asia, and Australia.

Most bauxite is available very near to the surface and thus easily mined relative to other ores. Nevertheless, a number of physical, chemical, biological, ergonomic, and psychosocial hazards exist throughout the mining process[1].

Physical Hazards:

Physical hazards include noise, heat and humidity, ergonomics, including vibration, naturally occurring radioactive material, and ultraviolet radiation. The potential for traumatic injury is a reality that compels operating locations to assure the proximate availability of skilled emergency medical facilities. Noise from sources such as earth-moving equipment, blasting, drilling, and crushing is ever present. Consequently, noise-induced hearing loss is a significant risk to be managed, and robust hearing conservation programs are essential. The climate of tropical mining locations, with its inherent high ambient heat and humidity, can lead to heat-related illnesses; thus, regular employee awareness programmes and control strategies are necessary.

Operators of heavy equipment and machinery are subject to whole-body vibration, which can contribute to their spinal disorders. Naturally occurring radioactive material is present in bauxite at very low levels and transfers to the solid residue stream during refining, being absent in the alumina end product. This latter hazard must be considered and monitored. Ultraviolet radiation exposure, logically more pronounced, given the concentration of bauxite mining activity in tropical zones, can contribute to the occurrence of basal cell carcinoma. Generally, accepted control measures include enclosed mobile equipment cabs, creative scheduling to avoid midday sun exposure, and proper protective clothing and sunscreen.

Chemical Hazards:

Chemical hazards are few because bauxite per se is generally considered to be biologically inert. In the occupational hygiene [illegible] categorized as a nuisance dust. Epidemiological studies of contemporary dust exposures in well-managed mining operations seem not to be associated with either clinically significant negative lung function impacts or pneumoconiosis. Trace quantities of beryllium and other metals are present in some bauxite; however, these have not been associated with adverse health impacts in those involved in the mining industry.

Additional Hazards:

Additional hazards include biological, ergonomic, fatigue, and psychosocial factors. Communicable diseases like malaria and dengue fever, in some areas, must be anticipated and addressed through appropriate mosquito and other vector control efforts, chemoprophylaxis, early diagnosis & treatment, employee education, and travel medicine consultation. Ergonomic hazards are minimized, because mining has matured to a highly mechanized state. Fatigue, however, is an increasingly relevant concern owing to extended shifts and overtime, and the implementation of fatigue risk management programs is growing within the industry. Psychosocial factors, including alcohol and drug abuse, are compounded by isolation, social change, and the lack of health care and other usual social amenities in some mining settings and should also be considered and addressed.

Alumina Refining Process and Associated Occupational Health Hazards and Risks

Alumina refining process transforms bauxite ore to calcined alumina (Al_2O_3). This extraction method, known as the Bayer Process, occurs through a progressive series of steps: crushing of the ore, digestion in a sodium hydroxide solution, clarification to remove solid waste materials, precipitation of solid hydrated alumina, and calcination to drive off water. Digestion requires large quantities of caustic soda, the signature chemical hazard linked to the refining process. Hazardous waste material Red Mud is generated in the refining process, which needs to be stored properly in a nearby pond for safety, health and environmental considerations. Red Mud needs to be handled carefully as it is caustic in nature. It needs to be utilized for the production of value-added items. Red Mud is rich in iron content and is considered as a very good source for recovering iron. Several R&D efforts have been made by the researchers to find out suitable avenues for scientific & technological applications of Red Mud. Several other important physical, chemical, biological, ergonomic, and psychosocial hazards exist, which are required to be tackled with great efficacy[1].

Physical Hazards:

Physical hazards include noise, heat and humidity, vibration, ergonomic and ultraviolet radiation exposure. Minor traumatic injuries, particularly in hands and fingers, are not uncommon; however, the occurrence of major traumatic events is rare. The presence of adequately equipped on-site emergency response and medical personnel is therefore highly desirable. Noise is a

ubiquitous hazard throughout the alumina refining process and noise-induced hearing loss remains an unfortunate, but still prevalent occupational illness for alumina refinery workers. Aggressive hearing conservation programs are essential. Best-practice programs incorporate quantitative hearing protection fit-testing and emerging technologies that use the personal noise dosimetry with real-time notification of daily exposure limit exceedance. Vibrating hand tools are frequently used within refineries, with hand-arm vibration syndrome occasionally manifesting in the workforce.

Chemical Hazards:

Chemical hazards include alumina and bauxite dusts, caustic soda and diesel exhaust fumes. Cancer incidence and mortality studies are very limited. Analyses using an internal comparison population showed no excess cancer risk of any type with bauxite or alumina exposure.

With strong alkalis (mostly NaOH) present throughout the alumina refining process, chemical splashes and spills remain a concern. Serious burns of skin and eyes are possible. Traditional emergency showers and eyewash stations using water are being augmented with more contemporary first aid agents, which are establishing evidence for safety and efficacy.

Additional Hazards:

Thus, conventional health and safety practices are very much essential for controlling risks, which are of paramount importance. Diesel-powered mobile equipment used, for example, inside alumina refinery tank for de-scaling generates diesel particulates, exposure to which must be controlled. Welding-fume control through standard ventilation and respiratory protection is important. Residual asbestos may be present in older refineries and must be managed appropriately to protect against worker exposures. The presence of organic matter in some bauxite can produce volatile organic compounds during the digestion process. Volatile organic compounds, with associated odour and irritation, are issues of potential concern both to the employees and to local communities. Since alumina refineries are generally co-located in relative geographic proximity to bauxite mines, the same environmental ambient concerns relating to heat and humidity, communicable disease, psychological factors, and ultraviolet light, apply, as do their respective control strategies.

Aluminium Smelting Process and Associated Occupational Health Hazards and Risks

Aluminium is obtained from alumina through the Hall-Heroult Electrolysis Process. This entails an electrochemical process involving long lines (some more than a kilometre in length) of electrolytic cells, or pots that use low-voltage, high-amperage electricity to produce aluminium metal from alumina (aluminium oxide). The Hall-Heroult Process was invented in 1886 and has remained fundamentally unchanged since that time.

In this process, molten aluminium is produced by electrolytic reduction of alumina, dissolved in a molten fluoride electrolyte, consisting mainly of cryolite, within a series of electrolytic cells or "pots." The pots are carbon lined and serve as the cathode to the electrolysis process. Carbon Anodes are produced by a separate process. There are two main types of cells used in the aluminium production. The Søderberg Cell has been the dominant technology for many years since its initial use in the early part of the twentieth century. However, the more common type in operation today is known as the Prebake Cell. In the former, the anode is made from a mixture of Petroleum Coke and Coal Tar Pitch and contains about twice the pitch content used for making Prebaked Anodes. Small briquettes of Anode Paste are added regularly at the top of the Søderberg Cell and the anode bakes in situ. In the Prebake Cell, anodes are made from a mixture of Petroleum Coke, Coal Tar Pitch, and anode material termed "butts" that represents remnant anode removed from the cell during anode changing. Anodes are consumed during the electrolytic process and are removed from the cell before they are completely used up. Prebake Anodes derive their name from the fact that such anodes are prebaked in special Anode-Baking Furnaces at about 1150°C to 1200°C, causing the pitch to carbonize and forming strong and dense anode blocks.

Søderberg cells have lower current efficiency and greater difficulty in collecting anode-baking fumes, especially Polycyclic Aromatic Hydrocarbons (PAHs). These hydrocarbons are mainly volatiles from the pitch used in the anode paste. Polycyclic Aromatic Hydrocarbon consists of many different organic compounds, which have been shown to be carcinogenic.

Alumina has three basic roles in the smelting process:

(i) As a feed for the cell, alumina may be added intermittently (in older cell types) or in measured quantities at short intervals usually via a point breaker feeder system.

(ii) As a thermal insulator on top of both the cell crust and the carbon anodes.

(iii) To help as a scrubbing medium in the cleaning of captured cell gases. Activated alumina, which contains the residual fluoride, is then used as a feed for the reduction process. In fact, it has a positive impact on cell chemistry and process efficiency over non-activated alumina.

Power, a major input for the electrolytic cells, comes from four main generating sources. Coal (50%) and hydroelectric (40%) provide the greatest contribution, with natural gas (8%) and nuclear (2%) sources contributing the remainder.

The electrolyte consists of mainly cryolite and smaller amounts of aluminium fluoride, calcium fluoride and alumina and [illegible] fluoride noted.

Physical Hazards:

Physical hazards associated with all heavy manufacturing industries are common during aluminium smelting. Chief among these hazards are heat stress, noise and ergonomic and electromagnetic fields (EMFs). Within smelting operations, heat stress occurs because of high levels of process-generated heat, which is compounded by ambient heat exposure, metabolic demands associated with the most common tasks involved (particularly within pot rooms) and the requisite use of personal protective equipment and clothing.

Both general and job-specific controls for heat stress exposures should be considered and implemented based on the results of exposure assessments. Acclimatization protocols remain an important component of heat stress management. Baseline and preheat season medical screening to identify personal risk factors for heat intolerance, emergency response planning, and worker training on early recognition of heat-related illness symptoms are additional components of a comprehensive program. For job-specific exposures, engineering and administrative controls are often necessary, and may include the use of personal cooling methods of heat stress control.

Noise is arguably the most prevalent occupational hazard within the aluminium industry, as it is for most other manufacturing settings. Yet, noise is often subordinated to other hazards, perhaps because of its omnipresence within the industry, the delayed onset of perceptible impact, perceived mild impact as an occupational illness, and difficulty in differentiating occupational from non-occupational impacts.

Both auditory (noise-induced hearing loss, acoustic trauma, and tinnitus) and with increasing recognition, non-auditory effects (communication interference, risk for injury, and cardiovascular impacts) can result from excessive occupational noise exposure. Studies of noise-exposed individuals within aluminium production facilities indicate an approximate 2% annual rate of standard threshold shifts[illegible]. A standard threshold shift is viewed as a significant change and is defined by the US Occupational Safety and Health Administration as an average decline of 10 dB or more at 2000, 3000, and 4000 Hz in a given ear, relative to a baseline audiogram; age correction is optional[illegible].

Noise-related injury risk is thought primarily to be related to communication interference and the inability to detect safety-warning signals[illegible]. Both animal studies and epidemiological studies of noise-exposed workers show acute physiological effects on the cardiovascular system, increased blood pressure and heart rate, cardiac rhythm disturbances, and increased cardiovascular workload via stimulated stress responses and cortisol/catecholamine releases and are hypothesized to increase risk for acute myocardial infarction or sudden death[illegible].

[illegible] ...tion technology [illegible] to [illegible]

electrochemical reduction process within the electrolytic cells (pots) found in pot rooms. This necessary low-voltage, high-amperage current, used to create the electric charge between the anodes and cathodes of the pots, is generated within smelter co located rectifier yards through the conversion of incoming Alternating Current electricity. Pot room workers, electricians, and maintenance personnel are thus potentially exposed to EMFs as an unavoidable physical hazard. However, measured levels of EMF exposure in pot rooms and rodding areas are below existing Occupational Exposure Limits (OELs). Epidemiological studies exploring the potential health impacts on aluminium industry workers with EMF exposure are very limited. However, to date, no relationships have been identified in preliminary studies looking at EMF exposure and cancer risk, sick leave because of musculoskeletal disorders and reproductive outcomes[6,8]. Magnetophosphenes, a visual phenomenon manifesting as the sensation of light flashes in one's vision caused by inducing electric currents stimulating the retina[illegible] have also been noted as occurring in aluminium smelter workers.

A number of traditional ergonomic stressors exist within aluminium smelting and refining. However, there are few published studies detailing the nature, extent, and programmatic intervention focused on such risks. Nevertheless, published data do exist within the industry, demonstrating a robust injury risk reduction when targeted ergonomic hazards are identified and systematically controlled[8]. In addition, the International Aluminium Institute, through a collaborative effort by the International Council on Mining and Metals, has produced health metrics guidance, which recognizes the importance of including ergonomics as a key leading indicator[9].

Respiratory Disorders:

As with other industrial settings, inhalation hazards represent the most common mechanism for potentially injurious exposure within aluminium production. There is a long history of academic study related to respiratory disorders among aluminium smelter workers, particularly for those, whose primary tasks occur in pot rooms. Thus, the literature base is replete.

Much of the early literature has its origins in the study of Norwegian and Canadian smelter workers, as primary aluminium production has been a long-standing core industry in these regions. These were primarily case reports and prevalence studies. More recently, Australian, European, and the U.S. researchers have contributed additional important data to the overall understanding of the respiratory health of aluminium production workers.

Respiratory health endpoints of interest have centered on the symptoms of cough, wheeze, and rhinitis, as well as the more quantifiable presence of obstructive or restrictive lung disease. Asthma in the primary aluminium industry, colloquially called "pot room asthma," however, has been of particular interest and study and is recognized as a condition somewhat specific to the industry.

Robust longitudinal studies have more consistently shown elevated rates of both nonspecific respiratory complaints as well as diagnosable asthma in the pot room versus non-pot room workers. Statutory occupational disease reporting in many countries—asthma in this context—has been useful in corroborating epidemiological findings and suggests that pot room asthma cases continue to occur, albeit at much reduced rates as compared with historical levels. This reduced incidence over the last decade or so directly parallels concurrent reductions in pot room dust and gas exposures over the same time course.

Mechanistically, pot room asthma has most consistently been linked to fluoride exposures in dose-response fashion, dating to the 1930s. Nevertheless, the definitive causative agent or agents have not been unequivocally determined. The relative contribution of isolated peak, repeated peak, or chronic low-level exposures to fluorides on the development of pot room asthma remains uncertain.

Within the broad construct of occupational asthma definitions, pot room asthma is generally viewed as an irritant, non-immunological form of work-related or work-exacerbated asthma. The International Aluminium Institute (IAI) Health Committee has developed criteria for the diagnosis of this condition[10].

Follow-up studies of subjects with pot room asthma indicate that, as with other forms of work-related asthma, symptoms may persist even after removal from further pot room exposure. Thus, worker education, rigorous medical surveillance, and prompt removal from exposure on early symptom recognition are essential to the most favourable prognosis.

Various forms of diffuse parenchymal lung disease have also been associated with aluminium production and aluminium itself[11]. A recognition that metallic aluminium powder and aluminium oxide can lead to the development of lung disease dates to the 1930s. Historical references to aluminosis (Shaver disease) attributed to high concentrations of alumina and silica among alumina abrasive manufacturing workers appeared in 1947. Aluminium-induced granulomatous lung disease has also been reported and is distinguished from sarcoidosis by the presence of aluminium within the granulomas.

The existing human epidemiological data suggest aluminium is — in the vast circumstances — only a nuisance dust (occupationally), with rare idiosyncratic occurrences of pulmonary fibrosis in susceptible individuals[11].

Cancer

There is epidemiological evidence for a causal connection between exposures to specific agents during primary aluminium production processes and certain cancers. Most of what is known relates to Soderberg operations or mixed Soderberg/Prebake operations. There have been significantly increased lung and bladder cancer risks reported in Soderberg workers from several countries but not all. Polycyclic Aromatic Hydrocarbons (PAHs) have been the putative exposure agent linked to these cancers. In Prebake Smelters, the main exposure to PAHs occurs during the manufacture of the anode, and once in situ within the pot additional release of PAHs from prebake anodes is low. In contrast, exposure to PAHs within Soderberg smelters occurs during the operation of the cell; thus, all pot room workers are potentially exposed, including during the relining of cathodes. Many PAHs are present and arise mainly from the coal tar binder or pitch. Benzo (a) pyrene (BaP) is often used as a good measure of exposure for the common PAHs seen in pot rooms. Observed lung and bladder cancer risks increase with cumulative exposure to BaP even after adjustment for smoking.

It is clear that exposures to PAHs are a significant cause of certain cancers. The etiology of other cancer types, however, is not as obvious, and while some risks are considered as significant ones, there is a definite need for further research in this area. Other potential exposures can include some metals (beryllium, mercury, nickel, vanadium etc.) and crystalline silica. Workers involved in pot lining can be exposed to tars and fluorides, and in some cases, asbestos.

In 2012, the International Agency for Research on Cancer published volume 100F "A Review of Human Carcinogens: Chemical Agents and Related Occupations," including a monograph titled "Occupational Exposures during Aluminium Production. This monograph notes that in IARC Monograph volume 92: "There was sufficient evidence from epidemiological studies of a carcinogenic effect of occupational exposure in aluminium production based on a relatively large number of studies that showed a consistent excess of cancer of the bladder and a somewhat less consistent excess of lung cancer." After further review of new data, the 2012 monograph concludes, in the final evaluation: "There is sufficient evidence in humans for the carcinogenicity of occupational exposures during aluminium production. Occupational exposures during aluminium production cause cancer of bladder, and of the lung. Occupational exposures during aluminium production are carcinogenic to humans (Group 1)." It is important to note, however, that the aluminium production exposure agent of focus in International Agency for Research on Cancer's determination is, specifically, PAHs.

Globally, many studies have been carried out with respect to cancer in the aluminium smelting industry[12]. It is a matter of great concern for the aluminium industry to address this important issue of cancer linked to aluminium smelting operation.

New Technologies

Inert Anodes (Non-Consumable Anodes)

One of the long-standing wishes of the industry has been to invent and use "inert" anodes, one that is chemically non reactive. Any future inert anode material must have several key [illegible]

reactivity in the electrolyte, show good chemical resistance, be physically stable, robust, and resistant to thermal shock. Other important factors include low wear rates, so that there is little need for repeated replacement — ideally, it should last the average length of the cell itself and have a purity level that prevents aluminium contamination.

Ongoing work on the quest for an inert anode is fuelled by cost savings when compared with the need for repeated replacement of consumable anodes, as well as potentially lower chronic material costs, improved cell environmental profiles, and fewer issues related to employee health through a lower job risk profile. Nevertheless, a direct replacement of inert anodes in existing electrolysis cells would lead to higher electricity consumption.

Two areas of interest remain in the forefront of inert anode development — metal alloy anodes, and "cermet" or ceramic/metal alloy mixtures. Unfortunately, issues remain to be resolved before either of these approaches can be considered as a proven technology. The potential advantages are so great; however, that serious work continued to be done toward the successful development of the inert anode.

Carbothermic Production of Aluminium

The Carbothermic process uses carbon and heat in a three-step process, rather than an electrolytic reduction process, to reduce alumina to aluminium. Like the inert anode, the Carbothermic process has gone through several iterations, starting with the initial attempts that produced Al-Cu alloys (1886) and later efforts that led to Al-Si alloys (from the 1920s to 1945). Recent efforts in several countries have focused on the production of pure aluminium. Currently, work is underway in Norway to produce an Al-C alloy, which could then be reduced to aluminium. These steps, the production of the Al-C alloy and the reduction of the alloy to aluminium, pose the greatest challenges.

To further complicate matters in the search for a successful Carbothermic process, considerable carbon monoxide (CO) will be released, leading to a 60% increase in overall CO_2 over current methods, through natural degradation. Even with a potential saving on electrical power, and assuming such savings would be applied to power generation from coal sources, a net increase of 40% will occur unless the CO_2 can be captured and used in other processes/uses.

Community and Environmental Health Considerations

Health Risk Assessment around Alumina Refineries

Health Risk Assessment (HRA) is a tool that can be used to estimate or predict the current or future health impact of chemical exposures on a population, such as the communities in which industrial operations are present. In recent years, HRA has been increasingly used to characterize potential health impacts to the c[illegible] [illegible] alumina refineries.

Because the overriding type of industrial emission for refineries is airborne chemicals, the centerpiece component of an HRA is an air dispersion modelling. Such modelling requires significant professional input to execute and interpret properly, and this methodology must be used to fully assess and characterize potential health impacts.

In Australia, best-practice HRA approaches and modelling techniques have been developed under the auspices of the Australian Aluminium Council. Health risk assessments are quite useful in assessing the potential impacts of a process or facility changes, and implemented engineering control measures, also for engaging appropriate community stakeholders.

Health Risk Assessment around Aluminium Smelters

Community health risks from smelter emissions, including noise, can be roughly assessed based on existing occupational health studies and on other community-based studies. Potential community health effects from aluminium smelters arise from the use of the Hall-Heroult production process, a process with well-defined hazards that have the potential to impact on the health of smelter workers.

Multiple hazards were identified in aluminium smelter workplaces, and their risks to workers were defined. The hazard profile included aluminium, aluminium oxide (Al_2O_3), beryllium, carbon monoxide (CO), carbon dioxide (CO_2), dust (reparable and inhalable), fluorides (particulate and gaseous), EMFs (static [direct current] and variable [alternating current]), nitrogen dioxide (NO_2), noise, PAHs (as benzene soluble matter and BaP), and sulphur dioxide (SO_2). Identified hazards were then assigned "to one of five risk categories: none; uncertain; low; medium; high."

To estimate the contribution of an industrial site to health impacts in a community is a challenge. There is first a need to understand the industrial processes themselves, then to have good data related to emissions to the community, and finally to be able to define the contribution of the specific industrial site being studied. In general, the more urban the area, the greater is the likelihood that there will be multiple industrial and perhaps natural environmental sources of the emissions under study. Another confounder is the use of occupational health data extrapolated to the general population, as these populations may differ significantly.

Potential health hazards that may also pose community health risks because of the proximity of the communities to aluminium smelters have been studied by many researchers. It has been observed that there is a potential for materials such as BaP, sulphur dioxide, particulate matter, fluorides, beryllium, and noise to pose community health risks. The range of risk magnitude, however, is widely dispersed on the basis of a number of both controllable and non-controllable factors including emission-control technologies, dispersion patterns and proximity to the facility.

Aluminium & Alzheimer Disease

Some researchers have linked Aluminium with Alzheimer Disease. This is an old age syndrome and people who die in this disease have aluminium in their brain cells. Intake of aluminium into the body system in the form of various medicines over the entire life cycle of a person is the root cause for this disease. Aluminium is not released in the excreta and gets deposited in the brain cells causing memory loss and thereby causing Alzheimer Disease. More research is required to establish conformity with the linkages between Aluminium and Alzheimer Disease.

Conclusion

Managing health and safety risks is paramount at all steps in the aluminium production process. There are many well-studied and characterized occupational health hazards and risks within the primary aluminium production industry. Based on various environmental and technical factors, some of these risks may also extend to local communities in selected circumstances — although the evidence for this is less clear. Rigorous health protection programs have generally been implemented throughout the industry to address & control, to the extent feasible, the identified hazards and risks. These include comprehensive industrial hygiene and medical surveillance programs and the use of state-of-the-art technologies and approaches wherever possible. Improved process control, positive technological changes, and better planning have also lowered potential risks for local communities.

The Health Committee of the International Aluminium Institute (IAI) has been a key catalyst and facilitator in driving continual improvement and technological changes for the protection of workers in the aluminium industry and those people residing in surrounding communities, including the development of applicable industry-relevant health indicators. The IAI's Health Committee has also had, and continues to have, an interest in enhancing the scientific understanding of the roles played by aluminium with respect to human health.

State Pollution Control Boards, Central Pollution Control Board, Technology Suppliers, Equipment Suppliers, Engineering Consultancy Organizations, State Govt. Agencies, Central Govt. Agencies, Concerned Aluminium Company, Local Communities and all such stakeholders have important roles to play to address such issues, which have a great societal impact.

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Waste to Wealth: Production of Ferro Nickel from Red Mud and Nickel Spent Catalyst Blend

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Abstract

Keywords: Red mud; Nickel Spent Catalyst; Reduction Roasting, Smelting, Ferro-Nickel,

Red Mud of Indian origin contains around 50% plus of Fe_2O_3 depending on the source of bauxite and is considered as a hazardous waste for the Alumina Industry. For production of one tonne of Alumina employing the time tested Bayer's Process, around two tonnes of Red Mud is generated from three tonnes of Bauxite. No suitable avenues for bulk utilization of Red Mud have so far emerged.

Nickel Spent Catalyst is generated in huge quantities in Indian Petrochemical Plants more than 20,500 tonnes per annum and is considered as a waste. Regeneration of these spent catalysts, after many cycles of operation, is not possible by ordinary techniques and it poses significant waste disposal problem. This waste material contains valuable metal like Nickel.

In the present study, efforts have been made to produce Ferro-Nickel from the blend of Red Mud and Nickel Spent Catalyst by adopting pyro-metallurgical process which includes Reduction Roasting followed by Magnetic Separation and Smelting of the magnetic fractions rich in Nickel. Ferro-Nickel containing 4-10% Ni was produced with nickel recovery of 80-85%. In this paper, experimental data on production of value added product are furnished for utilization of waste materials like Red Mud and Nickel Spent Catalyst.

1.0 Introduction

Red Mud, a by-product generated from the caustic leaching of bauxite to produce alumina in the Bayer Process, causes serious environmental problems and is considered as a hazardous industrial waste. During digestion of bauxite around two tons of Red Mud per one ton of alumina is produced. In India, various alumina produces viz. NALCO, BALCO, HINDALCO, INDAL, MALCO and VEDANT produce around 2 million tonne per annum of red mud which is stored by the companies in nearby ponds specifically made for the purpose which contains around 30-50 % iron. Utilization of Red Mud for production of cement, tiles, bricks and blocks etc has been tried by many researchers. However these efforts have resulted in partial utilization of Red Mud and the problem of bulk utilization of Red Mud still remains a challenge.

Further more nickel spent catalyst is a waste material generated in huge quantity in the orde of more than 25,000 tonnes per annum from Petrochemical products and posses significant disposal

problems causing serious environmental hazards. This material is a good source of nickel containing around 6.17% NiO.

Since iron is a major constituent of Red Mud, it was thought prudent to utilise iron values in the form of ferro-nickel from the blend of red mud and nickel spent catalyst of petroleum refineries utilizing the state-of-the-art Reduction roasting followed by magnetic separation and smelting. This novel process will help in production of ferro nickel which can be utilized for steel making. By employing this technology, techno-economic feasibility for bulk utilization of Red Mud and another waste material- nickel spent catalyst can very well be established, thereby signifying the importance of production of wealth from waste materials.

1.1 Reduction of Fe_2O_3 present in Red Mud and NiO in nickel spent catalyst by Carbon: Fundamental Principles

Reduction roasting is an effective unit operation in the treatment of iron oxide present in red mud and nickel oxide present in nickel spent catalyst at an elevated temperature, which is carried out in the presence of carbon. Oxides of iron and nickel are reduced by gaseous reductant (CO) formed as a result of reaction between carbon and oxygen as per the principle of Boudward Reaction. The reduction mechanism is represented by the following equations.[1-5].



$$8FeO\,OH + SiO_2 + 2C \longrightarrow Fe_2SiO_4 + 2Fe_3O_4 + 4H_2O + 2CO \quad (1)$$



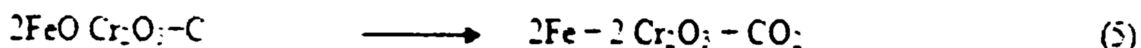
$$4Fe_2O_3 + C + SiO_2 \longrightarrow Fe_2SiO_4 + 2Fe_3O_4 + CO_2 \quad (2)$$



$$4FeO\,OH + C \longrightarrow 4FeO + CO_2 + CO_2 \quad (3)$$



$$2Fe_2O_3 + C \longrightarrow 4FeO + CO_2 \quad (4)$$



$$2FeO\,Cr_2O_3 + C \longrightarrow 2Fe + 2Cr_2O_3 + CO_2 \quad (5)$$



$$2FeO\,Cr_2O_3 + S \longrightarrow 2Fe + 2Cr_2O_3 + SO_2 \quad (6)$$

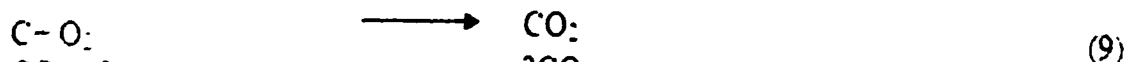


$$4FeO\,OH + SiO_2 + 2C \longrightarrow Fe_2SiO_4 + 2Fe + 2H_2O + 2CO_2 \quad (7)$$



$$2Fe_2O_3 + SiO_2 + 2C \longrightarrow Fe_2SiO_4 + 2Fe + 2CO_2 \quad (8)$$

Boudward Reaction



$$C + O_2 \longrightarrow CO_2 \quad (9)$$



$$CO_2 + C \longrightarrow 2CO \quad (10)$$

The main purpose of carrying out reduction roasting is the conversion of the iron oxide present in red mud into magnetite phase, so that it can be easily removed magnetically. Since the iron oxide in red mud and nickel oxide in nickel spent catalyst are blended together, the adoption of reduction roasting technique will be more appropriate to separate out the iron and nickel from the other associated gangue materials in the blend. The iron and nickel concentrate thus obtained by reduction roasting followed by magnetic separation route may be advantageous to enrich nickel content in reduced material. This reduced material then will be suitable feed materials for the production of ferro-nickel.

Other parts of the world utilize lateritic ore containing 1.37 to 2.80 % Ni for production of ferro-nickel as furnished in Table-1. However, in the present investigation, efforts have been made to produce ferro- nickel of the grade 4-25% nickel from the blend of red mud and nickel spent catalyst following a standard pyro-metallurgical process which includes reduction roasting followed by magnetic separation and smelting of the magnetic fraction rich in nickel using induction furnace facility at IMMT, Bhubaneswar.

Table 1: Composition of Lateritic ores used in Fe-Ni production in different countries.

Plant and Source of Ore	Composition of Lateritic Ore			Grade of Fe-Ni
	Ni%	Fe%	Fe/Ni	Ni%
1. Pacific Metal Co.Ltd., Japan (Philippines)	1.37	28.30	20.66	24 – 30
2. Marro do Niquel S.A., Brazil	2.00	6.50	3.25	30.00
3. S.A. Le Nickel, Doniamboo, New Caledonia	2.80	13.00	4.64	22-28
4. Sumitomo Metal and Mining Co., Japan (New Calendinia Ore)	1.46	1.63	1.12	27
5. P.T. International Nickel, Indonesia	1.62	14.10	8.70	-
6. Kovadarei, Yugoslavia	1.57	10.60	6.75	25.00
7. Hana Nickel Smelting Co., Riddle, Oregon	1.65	12	7.27	47.00
8. Larco, Greece	1.70	38.00	22.35	22-33

2.0 Experimental

2.1 Raw Materials

2.1.1 Red Mud

As a case study, red mud from NALCO, a Navaratna Company under Government of India, was used for conducting the experiments. NALCO has set up Asia's largest integrated Alumina-Aluminum complex in the state of Odisha, India and produces 15,75,000 MT of alumina per annum. In the process, about 31,50,000 MT of Red Mud is generated. NALCO, being the major player in Asia, in the field of Bauxite, alumina, aluminium and related products, it was envisaged to focus the study taking in to account the red mud generated by the company as the by product utilizing the Bayer's Process for production of alumina from bauxite,. The Red Mud of NALCO origin was used as the principal raw material for the present study. The chemical analysis of NALCO Red Mud is furnished in Table 2.

2.1.2 Nickel Spent Catalyst

Nickel is used as a catalyst in petrochemical plants because of its lower cost as compared to other competitive substitute and the spent catalyst is generated in huge quantity in the order of 25,000 tonnes per annum. Regeneration of these spent catalysts after many cycles of use is not possible by ordinary techniques and it poses significant waste disposal problems causing environmental hazards. This material contains valuable metal like nickel. The chemical analysis of nickel spent catalyst used for the present study is presented in Table-2.

2.1.3 The blend of Red Mud and Nickel Spent Catalyst

Efforts have been made for preparation of suitable blend comprising red mud and nickel spent catalyst for production of ferro –nickel as compared to the nickel content generally available in the world in different lateritic ores as feed materials. The blend ratio of red mud/ nickel spent catalyst of 50/50,60/40,70/30 and 80/20 have been selected taking into consideration the NiO wt% in the blend to be in the range of 3.085 to 1.234 respectively (Table-2). The Fe_2O_3 wt% present in the blend is comparable with the various nickel bearing lateritic ores used as feed materials for the production of ferro-nickel by the leading ferro-nickel producers of the world as shown in Table-1.
In addition to carbon used as reductant in reduction roasting, sulphur present in the blend acts as a catalytic reducing agent which enhances the reduction process of oxides of iron and nickel present in the blend without being detrimental to the process. In the reduction roasting process, sulphur is removed in the form of SO_2 and the reduced product becomes free from sulphur.

2.2 Experimental Details

As a case study, the blend composition ratio of 60/40 as shown in Table -2 was undertaken for the reduction roasting experiments in Down Draught Pan Sintering Furnace (Fig-1).

Table-2: Chemical Composition of the blend of Red Mud and Nickel Spent Catalyst (wt.%)

Sl.No	Constituents	Red Mud	Nickel Spent Catalyst	Red Mud/ Nickel Spent Catalyst Blend Composition			
				50/50	60/40	70/30	80/20
1	Fe_2O_3	55.20	3.00	29.1	34.32	39.54	44.76
2	NiO	-	6.17	3.085	2.468	1.851	1.234
3	MoO	-	24.50	12.25	9.8	7.35	4.9
4	CaO	1.36	1.93	1.645	1.588	1.531	1.474
5	SiO_2	6.32	10.00	8.16	7.792	7.424	7.056
6	Al_2O_3	16.53	49.33	32.93	29.65	26.37	23.09
7	MgO	0.21	-	0.105	0.126	0.147	0.168
8	Na_2O	3.12	-	1.56	1.872	2.184	2.496
9	TiO_2	4.47	-	2.235	2.682	3.129	3.576
10	S	-	5.06	2.53	2.024	1.518	1.012
11	LOI	12.49	-	6.245	7.494	8.743	9.992

The blend of red mud and nickel spent catalyst having fines of size -150μ containing 2.468% NiO and 34.32% Fe_2O_3 was mixed properly with coke breeze powder of size -150μ containing 65% fixed carbon in required proportion. The mixture was granulated using 12% water in disc pelletiser. The pellets were then mixed with coarser size coke breeze (-2mm) and charged into the Down Draught Pan Sintering unit. The laboratory scale of pan sintering unit of size 10X10X310 mm size was used for the experiment. About 50gms of charcoal pieces were put on the top of the pan sintering unit for ignition. The bed height was maintained at 300-310 mm. Slow down draught suction was initially applied for a minute for uniform ignition and then the suction was increased to the required level.

A typical suction pressure and exit gas temperature profile during sintering has been shown in Fig-2.The sintered product was ground to 85% passing through 75μ in a ball mill along with water and then subjected to low intensity wet magnetic separation. The wet magnetic separation was carried out using low intensity drum separator manufactured by SALA. International, Sweden. The drum of magnetic separator is of 200mm diameter and 120mm width. The magnetic intensity was maintained at 2000gauss.The solid concentrate in the pulp is kept at 20-25%.The slurry was pumped into the drum at a rate of 300-400cc/minute. The speed of drum was maintained at 45rpm. Both magnetic and nonmagnetic fractions were collected separately, dried, weighed and analysed for nickel and iron. The results are given in Table-3.The mineralogical characterization of sintered blend materials has been shown in Fig. 3.The magnetic fraction rich in nickel is smelted in induction furnace containing an alumina crucible to produce ferro nickel (Fig-4). Smelting Analysis of Magnetic fraction of sintered product is shown in Table-4.

3.0 Results and Discussions

The main objective of the reduction roasting process is to convert Fe_2O_3 phase of iron present in the blend material of red mud and nickel spent catalyst into magnetite phase and separate it from gangue materials such as alumina, silica, etc. If the Fe_2O_3 phase of iron is converted into magnetite phase, then the Fe/ Ni ratio will increase, thereby diluting the nickel grade during smelting. To overcome this problem, pan sintering technique was employed to selectively reduce iron oxide and nickel oxide such that the magnetic fraction becomes rich in nickel content. The fundamental study reveals that nickel oxide reduction occurs more rapidly than iron oxide reduction.[6-8]

During pan sintering process, iron oxide reduces into magnetite, wustite and metallic iron forms. When this reduced product is subjected to magnetic separation, magnetite and metallic iron along with nickel are separated. A nickel-rich magnetic fraction is obtained and it becomes the feed material for the smelting reduction process. The results of magnetic separation studies are shown at Table 3. The underlying philosophy of the study reveals that the subsequent stages of magnetic separation of the magnetic fractions shows higher content of nickel.

The smelting reduction studies were carried out in an induction furnace using coke breeze fines as the reductant for production of ferro-nickel. The amount of reductant plays a vital role in smelting reduction process for selective reduction of iron for obtaining higher grade of ferro nickel [9-10]. Ferro-nickel containing various percentages of nickel therein can be produced by selectively reducing iron oxide by controlling the use of different percentage of reductant as shown in Table 4.

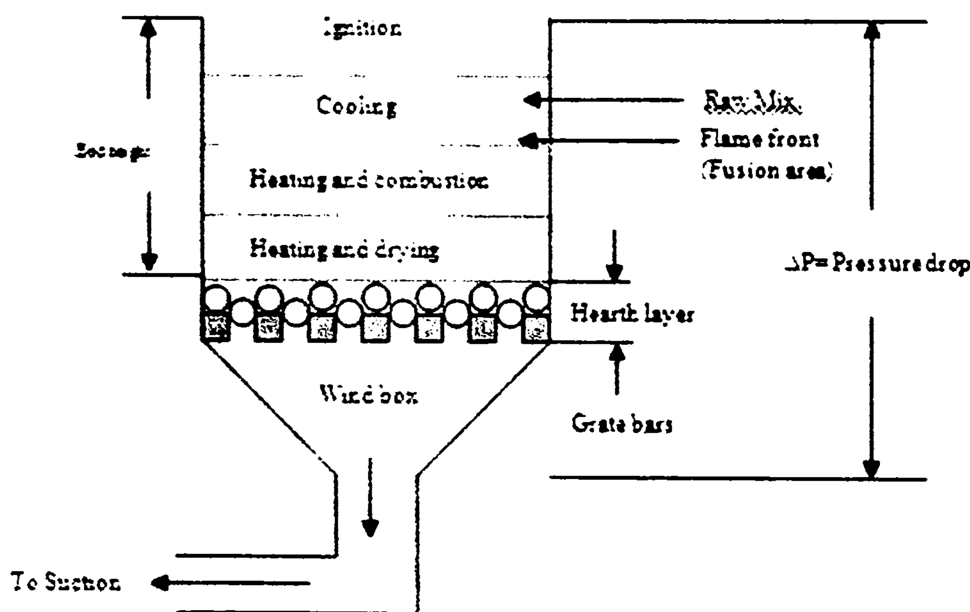


Fig. 1: Schematic Diagram of Down Draft Pan Sintering Furnace

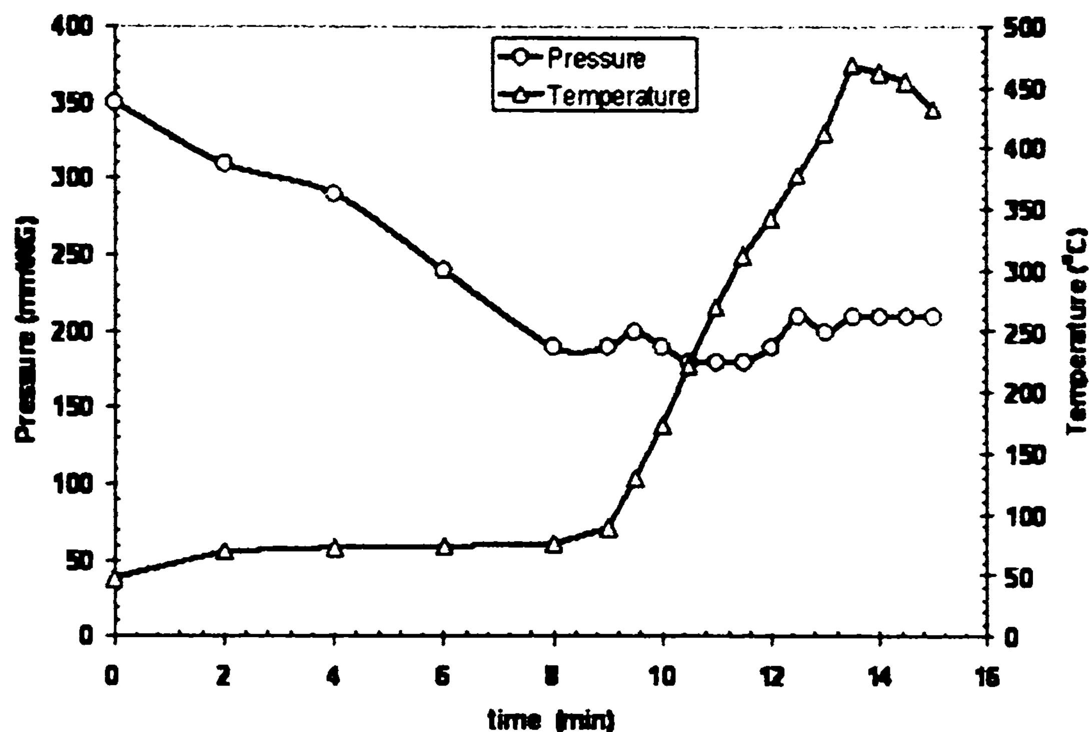


Fig.2. The exit temperature and pressure profile of the draught during reduction roasting process

Table 3: Results of low intensity magnetic separation of the blend of red mud and nickel spent catalyst.

Feed ground to 85% passing 75μm, intensity of magnetic field- 2000 gauss.

Details	Wt%	Fe%	Ni%	Fe/Ni	Ni Recovery	Fe Recovery
Roasted Feed*	100	42.33	2.52	20.06	100	100
Mag. Fraction	70	51.31	3.15	17.63	96.54	84.85
Non.Mag. Fraction	30	21.38	0.25	89.08	3.46	15.15

*Roasting Conditions:

1. Coke breeze inside the pellets (-150 μ) : 10% of blend mix.
2. Coke breeze out side pellets (-2mm) : 12% of blend mix.
3. Bed height : 300 – 310mm
4. Suction pressure : 300 mmWG
5. Time of sintering : 15-20 minutes

Table 4: Smelting Analysis of Magnetic fraction of sintered product.

Feed: Magnetic fraction of sinter product, containing 3.15 % Ni and 51.31 % Fe
Crucible in Induction furnace : Alumina
Temperature : 1550°C

Exp.No	Charcoal (%)	Alloy			Slag		
		Wt%	%Ni	%Fe	Wt%	%Ni	%Fe
1	4.2	3.70	25.00	76.80	96.30	0.075	22.480
2	7.5	30.00	6.42	91.60	70.00	0.250	40.210
3	10.0	36.00	5.58	93.30	65.00	0.490	16.20
4	10.0	42.00	4.28	86.57	58.00	0.150	6.140

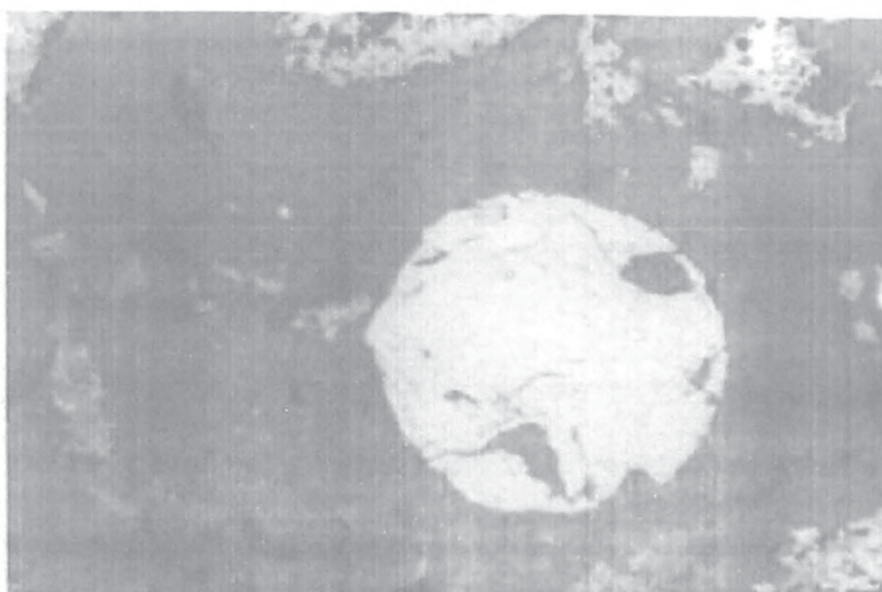


Fig. 3: The mineralogical characterization of sintered blend materials, Fe-Ni globule is distinctly spherical. Escolite developed as bright irregular patch.Lamellar esolution textures are common. Reflected light. Length of all photographs = 400 microns.

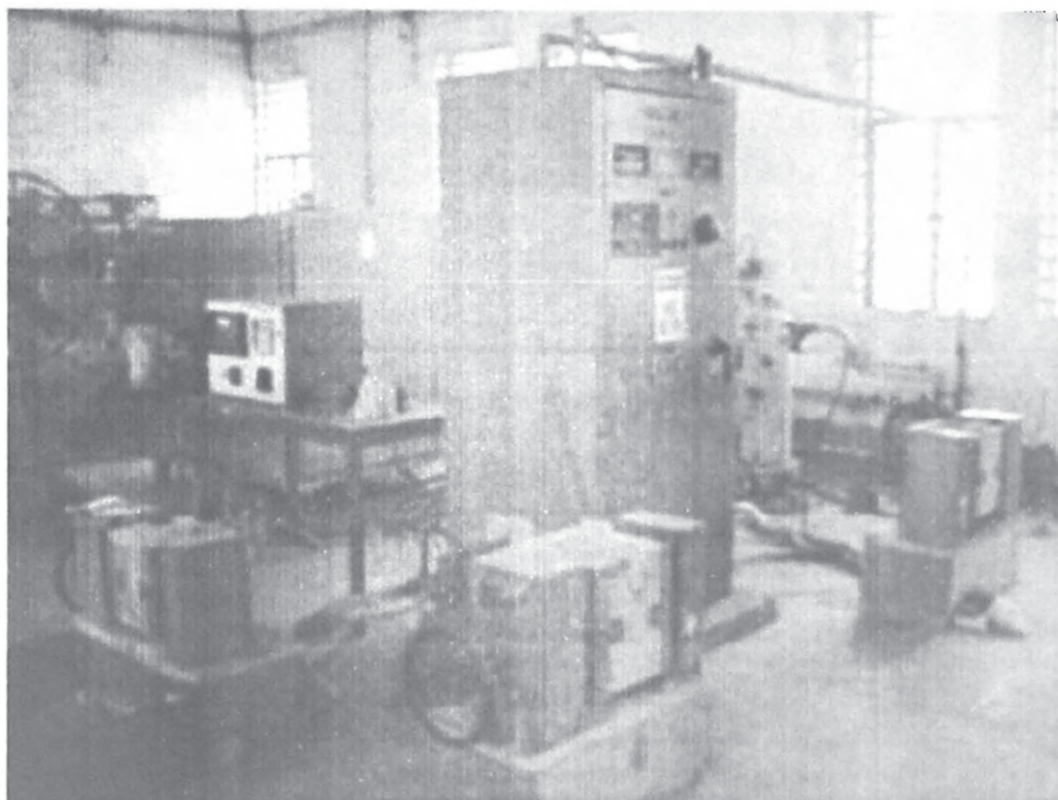


Fig. 4: 35 kVA Induction Furnace having three modules 5 kg, 10kg and 20 kg capacity

4.0 Conclusions

The following conclusions may be drawn from the above experimental findings.

A state-of-the-art reduction roasting process followed by magnetic separation and smelting techniques has been shown to produce ferro-nickel containing 4-10% nickel from the blend of red mud and nickel spent catalyst. The technology is environmentally friendly and zero-waste process accounting for complete conversion of blend of waste materials red mud and nickel spent catalyst for production of ferro-nickel.

It is possible to produce ferro-nickel from a suitable blend of red mud and nickel spent catalyst and the process so developed has novelty and uniqueness in character and can very well be exploited for techno-commercial realizations

5.0 Acknowledgement

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Recycling of Non-Ferrous Metals

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Environmental & Waste Management in Non-Ferrous Metals Sector

Recycling of Non-Ferrous Metals



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Non-ferrous metals (NFM) are used extensively across the globe. With the gradual depletion of primary resources, recycling of end of life products is, and will be the most preferred way to become the secondary source of NFM. Recycled non-ferrous scrap metals thus, are key to the metallurgy industry for the production of metals anew, thereby serving as renewable resource. Re-use not only leads to a cost-effective secondary production, but also reduces carbon footprint and conserves energy and minerals. Therefore, demand of recycled scrap is seen to rise in developed, as well as developing nations alike.

Notable researcher Dr. C. R. Mishra, in this article, throws light on the countries targeted by ReCoMap (a Regional Programme for Sustainable Management of the Coastal Zones of the Countries of the Indian Ocean), where NFM availability is limited. He has particularly emphasized on the pollution & waste creation/energy consumption/environmental degradation aspects of recycling NFM in these countries. In this article, he has mainly highlighted on recycling of two NFM – aluminium and lead and the associated risks with informal recycling. In addition, Dr. Mishra has also made a detailed discussion on recycling channels for WEE (Waste Electrical & Electronic Equipment) and the related aspects. He comes up with the rational or rather safer and greener processes & technologies of NFM recycling.

What are Non-Ferrous Metals?

What is commonly called Non-Ferrous Metals (NFM), to be differentiated from Ferrous Metals such as steel, cast iron and other alloys with iron such as stainless steel or galvanized steel, are primarily metal alloys made of aluminium, copper, tin, lead, zinc, chrome, gold, silver, etc. It is indeed quite rare to find rejects or waste of pure metals or else in very small quantities.

In fact, the professionals of this sector of activity distinguish three categories of non-ferrous metals.

(i) Basic metals: Aluminium, Copper, Lead, Zinc, Nickel, Chrome and Tin

(ii) Special metals: Germanium, Gallium, Barium, Tantalum, Indium, Vanadium, Terbium, Beryllium, Europium, Titanium, Ruthenium, Cobalt, Palladium, Manganese, Antimony, Bismuth, Cadmium, Selenium, Niobium, Vitrium, Rhodium, Mercury, Arsenic

(iii) Precious metals: Gold, Silver, Platinum

NFM are mostly found in [illegible] packaging vehicles

and industrial equipment, electronic components and domestic electrical appliances. The industries which use these recycled materials are mainly foundries, iron and steel industry and other heavy industries.

Nowadays, the material recovery undertaken, ensures 73 per cent of the needs in NFM for these industries and the recycling of products at the end of their life span represents 20 per cent of the needs.

The recycling of end of life products will be more and more sought as it becomes the only source of secondary non-ferrous metal. Indeed primary resources are declining, at least temporarily, due to the scarcity of new mining projects set up during the past years.

Ancient History

Non-ferrous metals were the first metals used by humans, for metallurgy. Gold, silver and copper existed in their native crystalline, yet metallic form. These crystals, though rare, are enough to attract the attention of humans. Less susceptible to oxygen than most other metals, they can be found even in weathered outcroppings. Copper was the first metal to be forged – it was soft enough to be fashioned into various objects by cold forging, and it could be melted in a crucible. Gold, silver and copper replaced some of the functions of other resources, such as wood and stone, owing to their ability to be shaped into various forms for different uses. Due to their rarity, these gold, silver and copper artifacts were treated as luxury items and handled with great care. The use of copper also heralded the transition from the Stone Age to the Copper Age. The Bronze Age, which succeeded the Copper Age, was again heralded by the invention of bronze, an alloy of copper with the non-ferrous metal tin.

Recycling & Pollution Control

Due to their extensive use, non-ferrous scrap metals are usually recycled. The secondary materials in scrap are vital to the metallurgy industry, as the production of new metals often needs them. Some recycling facilities re-smelt and recast non-ferrous materials; the dross is collected and stored onsite while the metal fumes are filtered and collected. Non-ferrous scrap metals are sourced from industrial scrap materials, particle emissions and obsolete technology (for example, copper cables) scrap.

Factors favouring the development of recycling of NFM

On the one hand, the production of primary ore is inexistent in several geographic regions. Recycling NFM, therefore, constitutes the only available "surface mine", which presents the advantage of being a renewable resource. In any case, the re-use of recovered material enables savings in cost of raw material.

On the other hand, the production of secondary material costs much lesser than the production of primary material from ore.

- Necessary investments are in average 3 or 4 times lesser than for refining
- Savings in energy consumption when compared to production of primary metal, is of the order of 60 to 80 per cent for copper and 90 to 98 per cent for aluminium, which represents a significant advantage in the context of present high energy costs and of constraints associated to CO_2 emission which are becoming higher in Europe

Beyond the present economic context, newly developed countries such as China, which use more and more of this type of production and which import recovered material, are meeting a demand which should go on rising. This industrial growth should bring China and India to increase their importation of material for recycling, first from industrialized countries, and then from developing countries which have not set up refining units and which are interested in the income derived from their sales.

Since 2002, the prices of NFM have not stopped increasing and more particularly, those of copper, which have risen to about 7 000€/T, reaching its highest level of the past 16 years. This spectacular increase in the price of primary and recycled NFM is due to the combination of several factors:

- The strong international demand, pulled by China and India and by industrialized countries, is in constant growth even if is attenuated by the present financial crisis affecting the automobile and construction sectors of activities
- The fall of the dollar against the other foreign currencies. The metals listed at LME have their prices automatically adjusted
- Supply and demand market regularly encountering shortages due to the rationing of the supply

In case of countries targeted by ReCoMap (a Regional Programme for Sustainable Management of the Coastal Zones of the Countries of the Indian Ocean), the available NFM is limited. The industrial sector and equipment suppliers, usually generators of this type of waste, are not much present and the consumption in equipment from which used goods could be produced, represents a weak resource in NFM.

Most of the studies regarding the characterization of Hazardous Household Waste (HHW) or Non-Hazardous Industrial Waste (NHIW) in developing countries, show that the fraction of NFM is less than 1 per cent of the total tonnage of waste in rural zones and comprised between 2 to 2.5 per cent in urban areas.

In these regions, it can be noted that the largest part of NFM is composed of basic metals, but an increasing attention is being brought to the growth of the electronic equipment and electrical appliances sector producing waste which involves not only ferrous metals and basic NFM, but also special metals and for the computer equipments, some precious metals.

Since recently, some industrialized and emerging countries among which Russia and Morocco, have closed their boundaries to the exportation of NFM for two main reasons: on the one hand, they want to avoid being deprived of a resource which can be useful for their industrial development, and on the other

hand, they realize that the uncontrolled development of recycling channels for NFM leads to organized thefts on private and public installations such as electrical lines.

The threat is much higher in developing countries, where populations are even more thriving to earn some income and where the supporting and control measures for recycling channels are low or inexistent.

Even if the available volume of NFM in targeted countries of ReCoMap is much less important than in industrialized countries, it nevertheless represents a resource, which should not be sold off on the export market and it is essential to highlight the fact that the recycling channels, formal or informal, should not remain pollution sources as is often the case nowadays in those countries.

Recycling options for Non-Ferrous Metals

In the coastal zones of the targeted countries of ReCoMap, we can differentiate two main configurations: the large urban industrialized zones and the rural areas.

The priority regions for ReCoMap are mostly rural and do have host industrial or other activities likely to generate massive amounts of NFM.

In fact, the major part of NFM is produced through consumer goods and electrical appliances, domestic or industrial, and it is for a large part already treated, often informally, by local operators, who are highly motivated by the commercial demand from India and China.

Even if there are no specific studies undertaken on the subject for the priority countries and regions of ReCoMap, experience acquired on similar sites lead us to think that most of the NFM are basic metals, generated by the automobile or naval sectors and of domestic equipment, and to a lesser extent, special and precious metals which are found in small quantities in residual waste from computer wares and electronic products which are encountering a fast development.

Most of data available, indicate a major predominance of aluminium and lead. Copper follows far behind but it may be due to the absence of regular notification at export.

Predominance of Aluminium and Special Metals

In the same way as for plastics, the system presently in force in targeted countries of ReCoMap, is essentially oriented towards sorted material, sometimes after a minor transformation (volumic reduction, melting in rough bars). Consequently, the value added is low for collection and sorting operators who are quite rarely the final beneficiary of the activity. However, this low added value is probably, partly compensated by the low taxation withheld by fiscal authorities who do not have the means for a strict control on this "merchandise" flow.

If the export sales of these materials bring some foreign currency, it is also clear that the optimization of sorting protocols, volume reduction and in some cases primary transformation, could provide sustainable employment and a better distribution of wealth between operators and waste managers.

In order to implement viable recycling options for NFM, technologies with high investment and environmental risks, as well as important volumes are required. No development in this TN solutions is done for complete recycling cycles but rather some methodologies are explained, aiming at the preliminary stages of recycling options.

- For some Waste Electrical and Electronic Equipment (WEEE), the principle for sorting operations and volume reduction which allow the sales of those products on the international market, will be presented
- For aluminium and lead, it will also be a question of optimization of the common practices of melting which often present hazards and risks for operators, their immediate environment and the users

Recycling of Aluminium

Risks associated with informal recycling of Aluminium

A certain number of initiatives for informal recycling of aluminium in developing countries are known and most of the recycling options present three main common features:

1. They recycle mostly aluminium from automobile engines
2. They produce mainly kitchen ware
3. They generate atmospheric pollution, as well as liquid and solid wastes and consume a high quantity of wood coal, hence contributing to deforestation

As a general rule, the foundries contain basic equipment such as:

- A storage zone for sand and the area for the preparation of moulds
- The forge blower and the melting pot with a storage and cooling zone for the residues
- The storage for wood coal and raw material

In terms of supply, the raw material arrives separated in two categories:

- Light aluminium
- Heavy aluminium

Light aluminium is generated through the consumption of beverage cans and food tins which are usually collected from dumpsites or deposit areas for domestic waste.

Heavy aluminium is mostly generated from scrap merchants or it is collected at mechanical workshops, aluminium joineries and dumpsites, where sorting is carried out by informal workers.

Despite this initial sorting, the melting of the material is often undertaken on mixed waste, without measurement and preparation, apart from some rough crushing or grinding of large pieces and crushing of small containers. Working conditions of these informal workers are very poor and it can be noted that a

large number of children and poor populations are employed for these tasks.

Melting is carried out in a pot made of assembled metal plates (covers of drums, recovered iron sheets) laid on a furnace fed with wood coal. It happens that the furnace is "improved" with an enclosure made of fireproof material such as clay mixed with slag (impure silicates). In any case, the forge blower is used to reach a temperature sufficient for the melting of aluminium i.e. 630 and 650°C. In these informal workshops, often set up in the open air and directly on the soil, devices for the recovery of combustion fumes or melting vapors do not exist, so much so that the totality of process gases are rejected in the atmosphere without any treatment.

Recent studies show the existence of the generation of DLCs (Dioxin-Like Compounds), more specifically PCDD (Poly Chlorinated Dibenzo-Dioxin) and of PCDF (Poly Chlorinated Dibenzo Furan). These POPs, which can be assimilated to dioxins and furans, are typical of combustion of mixed waste on dumpsites and present a proven toxicity level.

In the case of aluminium foundries, it is not only a concentration of atmospheric pollution, but also of soil and water pollution, as the slag is lixiviated by rain. Direct exposure to these pollutants, by gaseous or liquid transmission, is particularly damageable to human health and particularly to children.

The nature of the products generated by this recycling mode also constitutes a danger for users. Indeed, the kitchen ware which are manufactured, are composed of impure aluminium containing namely oxidized components which, despite the polishing with glass paper, will be progressively released to food contained in the kitchen ware.



Origin of supply of aluminium wastes

Rational process for the recycling of Aluminium

Industrial units which are dedicated to aluminium recycling and which comply with environmental norms imposed to that activity, proceed in three main steps:

1. Reception, identification and weighing of waste to be recycled
2. Sorting and purification of accepted material
3. Transformation

The first step is essential and relatively easy to set up and it enables the elimination of a large part of chemical and physical risks which could arise at shredding or electromagnetic separation stages and because of the mixing of unwanted material in the melting process.

The second step brings the guarantee of chemical standardization of the material which will be melted. It is also at this stage that micro pollutants will be removed by chemical (solvents, surfactants), mechanical (shredding) and electromagnetic (Foucault Current, Eddy Current Separator) means.

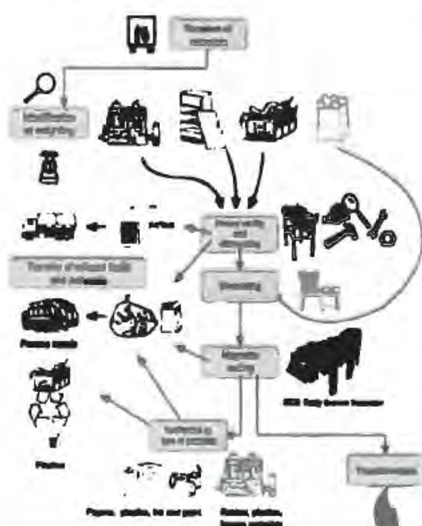
One of the steps of this process consists in putting the aluminium pieces after they have been shred and roughly purified in a tape conveyor with a separator, using the principle of Foucault current, for the separation of pure or nearly (alloys and oxides) aluminium particles from those rich in ferrous metal and unwanted NFM (e.g. Magnesium).

Environmental Control System (ECS) is a conveyor tape made with a particular magnetic field in the head, which is generated by high frequency polar wheel: when the non-ferrous metals come near to the magnetic field, they are lifted and "expulsed" to one appropriate collecting canal, while the inert materials freely fall down to another container. All iron till the smallest pieces, which differently from the non-ferrous metals, is kept by the magnetic rotor and downloaded in the proper container under the Eddy Current separator.

The transformation consists in two to three steps:

1. The production of bars considered as 'second melting' from reflection or arc furnace
2. Refining, which is an improved melting operation, integrating the use of metallic or metallo-organic salts, operation which can be combined with the production of bars of second melting
3. Lamination, which enables the production of plates and sheets corresponding to the standards established by industries

which manufacture mainly packaging or cylinder heads for the automobile industry



Schematic representation of the [illegible]



Schematic representation of the final step for the industrial production

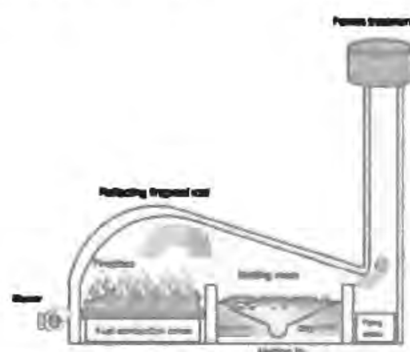
Aluminium generated in the priority regions of ReCoMap is largely composed of aluminium tins and cans and is as to date under exploited. We can note that these packaging have an interior plastic coating and that they are printed on their external face, which necessitates a chemical purification stage before the melting phase. It can also be underlined that a single such box contains 14 g of metal and that 36 per cent of new containers are made from recycled aluminium.

It is at the melting stage that the main physical and chemical phenomenon which allows the production of aluminium of high quality occurs, without oxides or other metallic trace elements.

Several technologies can be employed, but the most commonly used and also the most accessible in terms of technology transfer remains the reflection furnace. In this type of furnace, the fuel source can vary, but has to remain in a range where thermal energy produced has a high radiation (visible flames), and bituminous products have long been used for this purpose.

However, it is perfectly possible to use bricks made of paper/cardboard enriched with animal or vegetal fats or bricks made of dry compressed paper/cardboard to which sawdust and wood shavings are added. In fact, the thermal capacity of the furnace will depend on the conception of the reflective dome (shape and refraction), the ventilation is as important as it allows the optimization of the proportion of combustive agent for a given proportion of fuel.

The height and the diameter of the chimney are calculated based on the temperature of gases to be evacuated (melting vapors and combustion gas) and also on the passing through of gases in the filtration system



Schematic representation of a reflection furnace

A post combustion phase can be added in order to fix in a cyclone system (Venturi) the slag and flying ashes. In the case of wet filtration, the cyclone also plays the role of accelerator and suppressor.

The use of used tyres and plastics as fuel is highly polluting and should be proscribed except if a high technology system of smoke treatment is available. In any case, operators, who wish to optimize an existing installation or to set up a unit which includes melting of bars, are recommended to acquire the most adapted technical engineering.

The refining melting uses a mix of salts for the final treatment of aluminium of second melting. They hold the function of covering the metal against oxidation, or to remove the inclusions, the alkaline metals and the magnesium. Most of the saline exchanges are based on the binary systems KCl-NaCl or KCl-$MgCl_2$. The additives also include other chlorides, fluorides, nitrates, carbonates or sulphates.

Workers operating on aluminium recycling sites and exposed to fumes and melting vapors, as well as to particles emissions

(colloids), are subject to the development of emphysema and to pulmonary fibrosis. It is therefore of utmost importance to be equipped not only with an efficient system for treatment of fumes and vapors, but also of a regular aspiration protocol for dust generated through the process (finition and slag). It is also necessary to equip the workers with complete clothing, including gloves, protective glasses and filtering mask.

Recycling of Lead

Risks associated to informal recycling of Lead

In our targeted regions, the lead recovery activities rely essentially on the material found in vehicle batteries. Batteries are composed of a set of negative and positive plates, placed alternatively and isolated by separators. The elements of the battery are linked by a metallic connector which conducts electricity from one element to the other.

A typical lead battery consists of 17 per cent of metallic lead (metal), 50 per cent of lead oxide and sulphate, 24 per cent electrolyte (diluted sulphuric acids), 5 per cent of plastics and 4 per cent inert residuals. The electrodes are composed of lead oxides. The cathode is composed of lead sulphate and the anodes, of a lead alloy which can comprise antimony (main constituent), calcium, arsenic, copper, tin and selenium.



Section of an automobile battery and diagram showing its chemical composition

As far as recycling channels are concerned, two configurations are generally differentiated: the informal operators and the industrial Small & Medium Enterprises (SME) which can produce new batteries from recycled material. In both cases, and without presuming of a complete vertical integration, the process articulates through 5 main steps:

- The collection of batteries
- The draining of acids contained in batteries
- The shredding and separation of components
- The desulphurization and neutralization with production of Na_2SO_4
- The smelting and refining

Environmental risks associated to this activity can be analyzed specifically for each step of the process and the informal units are particularly subject to these risks.

For the informal operators, the activity starts with the search for batteries at garages and mechanical workshops around the transformation site. The present tendency seems to be the storage at garages but mainly at batteries selling points who find economic interest in selling this type of waste on the national or international NFM recycling market. Despite this tendency for grouping for export, the local options for the transformation of raw lead bars (un-refined and non-de-sulphurized) continue to work.

- The first action after collection is to drain the content of the batteries, most often anywhere, without any concern for the receiving body (soil, wetlands, rainwater drains, etc.). Risks of burning through skin contact are real and pollution has been proven due to the corrosive nature of the electrolyte, its content in soluble particles and in lead dust
- Once the battery is sent to the recycling site, it is opened with rudimentary tools and a manual separation is undertaken in order to separate the lead grills of the cardboard or of other elements
- Then the lead grills are cleaned to remove any remaining impurity trace. The solid waste and effluents resulting from this cleaning operation are special wastes which are highly toxic, but they are only considered as domestic wastes or equivalent and in the best scenario, are sent to the dumping site
- The cleaned lead grills are put in a pot to be melted at high temperatures. The fuel used is a mixture of wood, plastic residual material from batteries and other plastic wastes recovered from domestic waste
- To optimize the combustion, it is frequent that the oil drained is added to the above mixture which contributes to the increase of emission potential of PCDD/PCDF. The melting operation is realized in open air or under a shelter and there is no treatment for combustion smoke and melting vapors which result in direct atmospheric release
- Finally, the last phase consists in the cleaning of lead in the pot with water and to remove the rough bar obtained. The lead is sold locally around 0,3 € per kilogram



Deposit of plates extracted from batteries by an operator of the informal sector

When the combustion slag and the plastic waste are left in place, they create an active zone of lixiviation which generates deposits of heavy metals in soils. The transportation of metallic lead residuals, of lead oxides and sulphates into soil, is slow and the oxido reduction mechanisms are not very efficient. However, some plants are tolerant to these sources of pollution (e.g. some tubers) and lead colloids settle very quickly in wetlands which make bioaccumulation of this toxic metal possible.

Traditional fishermen are among the regular buyers and they usually transform the lead bars by fractioning and sometimes by re-melting and moulding, in order to make the appropriate weights to be used for nets or fishing lines.

At this stage, the cooling waters and water used for cleaning the bars are discharged directly in the natural environment and increase the pollution level of soils.

To conclude on this analysis of informal practices, it can be noted that if the process is simple and does not require high investment, the quality of the product is poor when compared to similar industrial products. Also, we can underline that the environmental costs is high, both for the receiving natural bodies and for operators, who are often exposed to risks of being affected by Satanism, encephalopathy and kidney lesions.

Rational processes for Lead recycling

Industrial units and SME involved in the recycling of lead, globally follow the same steps as informal recyclers, but with technologies which cause much lesser damage to the environment and to operators.

- First, batteries are collected in special waterproof containers in order to contain eventual acid discharge. The draining of the sulphuric acid (H_2SO_4) from the batteries is made by draining in an adapted tank equipped with a grill where batteries can be left until complete draining of the acid. The electrolytes are then filtered and titrated in a view to be sent as industrial components or to be enriched to be transformed in new electrolytes
- The second operation consists in the shredding and semi-mechanized sorting. Indeed, since the end of the 70's, the box and cover constituting the batteries, traditionally made of ebonite, are more commonly made of polypropylene nowadays. The shredding itself comprises generally 2 phases:
  1. Chipping and separation of macro particles of plastic and other unwanted material
  2. Fine shredding and sorting of plastic particles and other unwanted material

  The sorting is pneumatic or hydraulic and enables the recovery of a large fraction of plastic material under the form of reusable flakes (PP of envelopes and PVC or separators).

  Shredding operations and sorting are relatively simple to set up, but the core of the process which lies on the treatment of the mixture (desulphurization/ neutralization) and on the melting/refining, is based on a technology with significant investment and requires excellent technical capacities and a sophisticated measuring system. It must be noted that the desulphurization of the paste before the fusion, allows the avoidance of rejects of gas composed of sulphur and simplifies the treatment of fumes.
- During the third operation, the grills of the electrodes, the lead oxides and the lead sulphate, as well as the current conducts made of lead, will be treated before refining by melting. Indeed, the sulphur contained in the mixture before melting, must be eliminated in order to reduce sulphur emission during the melting operation

The desulphurization comprises the following reactions depending on the base component used:

1. Desulphurization: $PbSO_4+2NaOH$ brings to $Pb(OH)_2+Na_2SO_4$ or $PbSO_4+Na_2CO_3$ brings to $PbCO_3+Na_2SO_4$
2. Neutralization: $H_2SO_4+2NaOH$ brings to $2H_2O+Na_2SO_4$ or $H_2SO_4+Na_2CO_3$ brings to $H_2O+CO_2+Na_2SO_4$

- During the fourth and last operation, the desulphurized paste is directed towards the foundry and the refinery


Collection of batteries in water proof containers


A lead flow au fourn

The transformation consists in a first stage in a reduction of lead oxides in a rotating furnace at 950°C (sometimes in presence of coke at lower temperatures). The lead obtained is mostly an alloy lead-antimony, the composition of which is adjusted before the forming of bars. This type of alloy called "hard lead", is used for the manufacture of electrode grills and for internal and external connections. Antimony is added to lead in order to limit the corrosion of grills and increase the lifespan of accumulators.

The re-titration by addition of 'mother' alloys is carried out in hemispheric tanks of large capacity equipped with smoke capture devices. The smokes are filtered and the depolluted air is released in the atmosphere. The treatment undertaken, produces residual waste and refined ashes which are entirely recycled in the lead loads of the rotating furnace. Their quantity represents 8-10 per cent of the weight of treated metal. The refined and re-titrated metal is then pumped to a chain where bars are made or to a carousel, in order to be conditioned under the form of bars of about 30 kgs or blocks of 1 tonne.

It is important that the recovered lead, and in particular the batteries, are not melted in open air, but in specially equipped foundries. Workers must wear individual protective equipment such as face masks and must take a shower at the end of their work day, in order not to bring lead dust back home.

Recycling Channels for Waste Electrical & Electronic Equipment (WEEE)

This last category of NFM is relatively rare in the waste generated in priority regions of ReCoMap, as compared to the production of waste in industrialized and more advanced countries, but it is clear that its volume will be increasing in the coming years. It represents a complex source of pollution and a difficulty for waste managers, as many of these wastes are bulky and represent a visual nuisance and also accumulate rainwater, creating breeding and reproduction pockets for insects. Moreover, many of them contain toxic gases, liquids and other material which are difficult to extract.

If the WEEE had to be characterized in a global way, it can be retained that they present the common feature of modern consumption, complex and integrated, thus difficult to decompose into primary elements which are simpler to manage and to treat.

What is WEEE?

It is commonly admitted that WEEE include 10 groups of consumer goods and equipment. In view of the complexity of treatment of the WEEE, industrialized countries have recently put in place specific measures which aim at:

- Centralizing the treatment units in order to improve their cost-effectiveness by significantly increasing their treatment volume
- Optimizing the separate collection of different objects which form part of the list by setting up rules and incentives to this effect

If it is not always the case in developing countries, the initiative taken by industrialized countries, nevertheless, has indirect effects which must be underlined namely, the emergence of a new market for waste originating from WEEE or for some dismantled, sorted and eventually shredded components.

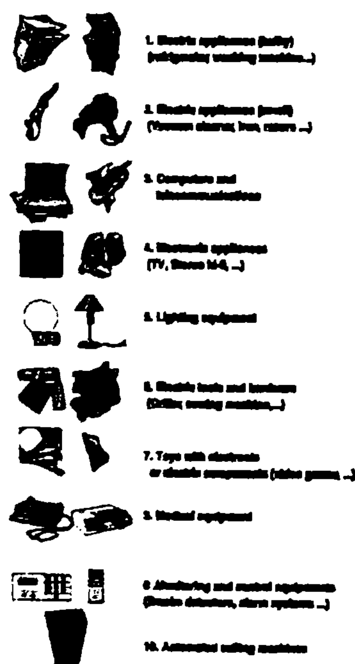
Unlike aluminium and lead waste, the WEEE are not rich in metal as most of them are mainly composed of plastics, which can be recycled but are more difficult to extract than from other types of plastics such as plastic bottles or tetra packs.

In fact, two elements qualify the WEEE for recycling:

1. They are neither biodegradable nor easy to treat as final waste, as they release heavy metals and volatile compounds
2. Their content in special and precious metals is low, but largely compensated by the large amount of this type of waste provided industrial recycling with high technology and high yield is implemented

Beyond the complexity of this recycling channel which, in Europe, has benefited from recent technologies and the concentration of financial means in a few industrial units, the opportunity to prepare the ground for a costly and heavy treatment by developing preliminary steps namely, the dismantling and manual sorting, can be seen in the ReCoMap targeted regions.

The 10 groups of WEEE are:



Difficulties and Necessity for WEEE Recycling

When the above list is analyzed, it can be seen that the collection and treatment of much diversified waste has to be dealt with, which are all complex and expensive to treat (land filling or incineration), if they are not recycled. Moreover, their hazardousness has been characterized along with a toxicity presumption, when they become waste for the following sensitive elements:

- Batteries and accumulators (toxic metallic compounds)
- CFC (Chlorofluorocarbons)
- Cathodic tubes (heavy metals, halogen compounds)
- PCB (Poly Chloro Biphenyl)
- Plastic material (non-degradable, product from the burning of POPs)
- Electronic cards (metal and toxic metallic compounds)

For example, it is admitted that Cathodic tubes are composed of special glass with high content in heavy metals, which can be differentiated in three zones:

1. The head of the tube
2. The glass of the cone
3. The base

The base and the cone are welded (sintered) with very high content in lead (75 per cent) and zinc (11 per cent).

The luminescent powder for the monochrome tubes are generally in zinc sulphur or cadmium and same for the coloured tubes but with additional products, such as yttrium and europium oxides, manganese, different phosphates, etc.

A sudden opening of the tubes results in a violent draught which pulls off the powder from the screen and puts them in suspension in the air. Their ingestion can be noxious. The other danger resides in the fact that this material, in presence of water, gets off its support and is put in suspension or in solution - it is the lixiviation phenomenon. It occurs namely, in certain dumpsites where the water run-off can pollute the rivers.

Another example is the recycling of electronic cards, which is very complex because of the diversity of components present. Electronic components are either plug-in (majority) or tin welded; the epoxy cards contain halogen components which can only support cold processes. The recycling process then follows the following steps:

STEP 1

In the first stage, it is necessary to detect the eventual toxic elements and to isolate them: mercury relay, PCB condensers, cell battery, and Cd/Ni battery, which must be treated as special wastes after labeling and containment.

STEP 2

The "heavy" elements are extracted from the cards: transformers, ferrite or copper coil, copper relay, ferrous or aluminium armature, connection cables, etc. It is indeed useless to treat these elements by electrochemical mode or others, as we know their composition and they can therefore be treated within a specialized recycling channel for NFM.

STEP 3

Some components, namely condensers, with composition which vary depending on the manufacturing year of the electronic card, are unwelded from the cards as they contain tantalum, a metal which oxides at 600°C with emission of toxic vapors.

STEP 4

Other components are unwelded from the cards to be shredded and treated with a hydro-metallurgic process in acid phase (successive acid baths), in order to recover residual special and precious metals (gold, silver, palladium, nickel, etc.).

STEP 5

Elements which have a golden surface (connectors, components, metals, processors splinters), are soaked in a cyanide solution (KCN or potassium cyanide), which leads to a gold cyanide solution. This highly toxic operation is undertaken under inert atmosphere and in depression, it enables the recovery of the gold metal.

STEP 6

The residual of products are epoxy resins (fiberglass and resins) to which copper films are sticked. Residuals from gold removing baths and residuals from welding with tin/lead are to be treated at later stages. They are incinerated in order to generate ashes, treated in acid phase in a view to extract the remaining precious metals and copper.

STEP 7

The inert waste are sent to a landfill site. The table in the next page, presents the average composition of an electronic card. It appears that a single unit contains only traces of special and precious metals, but it can be noted that there are more and more cards being generated nowadays.



Chemical composition of an electronic card

The demand for these metals is proportional to the expansion of the use of computers and electronic devices in our everyday life

Typical Composition of an Electronic Card

Material	Percentage (%)	Kg/Tonne
Epoxy & Fibre Glass Support	71.100	711.00
Copper	12.500	125.00
Tin	6.230	62.30
Iron	3.900	39.00
Lead	2.940	29.40
Nickel	1.310	13.10
Aluminium	0.590	5.90
Magnesium	0.049	0.49
Chromium	0.046	0.46
Gold	0.023	0.23
Silver	0.021	0.21
Antimony	0.020	0.20
Calcium	0.010	0.10
Platinum	0.008	0.08
Cadmium	0.006	0.06
Potassium	0.002	0.02

At the same time, the energy cost associated to the production of virgin metal or a metallic component made of virgin metal, is rising rapidly. Moreover, the environmental constraints are developing and putting pressure on industrials who know that their ecologic footprint is better when they use recycled material.

If it is not opportune to propose in the context of this TN that complete recycling channels are studied and installed in the priority regions of ReCoMap, it is nevertheless true that some preliminary phases could be set up prior to the transformation. Indeed, while industrialized countries invest in high technologies, it remains possible to set up workshops where some of the fractioning can be performed with profitability.

Elementary simplified fractioning of some WEEE

The following table indicates some options for the setting up of workshops with the objective of grouping, sorting and dismantling (primarily) the WEEE, in a view to negotiate the sales at optimized market price.

Conclusion

Resource conservation, waste minimization and pollution prevention should be the guiding principles for sustainable industrial growth. Proactive and preventive approaches will only make the NFM industry environment friendly. Recycling of metals should have the top priority since it is cost-effective, conserves minerals & energy and is also less polluting. Zero discharge concepts should be encouraged by the industry. Industry should work towards obtaining ISO: 14,001 certification which helps in addressing the environmental issues in a most comprehensive and economic way.

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Production of Green Direct Reduced Iron (DRI) from Red Mud of Indian Origin: A Novel Concept

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Abstract

Red Mud is considered as one of the hazardous waste materials generated during the processing of Bauxite for production of alumina using caustic soda employing the Bayer's Process. Presently Red Mud is discharged into the nearby Red Mud ponds which are located in the vicinity of alumina refineries. Red Mud of Indian Origin contains around 45-55% Fe_2O_3, 10.69% TiO_2, 20.42% Al_2O_3, 8.72% SiO_2 and other associated oxides in minor quantities. This composition of Red Mud can be considered as rich source of iron. No significant efforts have been made so far for exploitation of Red Mud for production of iron in commercial scale though some research activities have been reported.

R&D activities centered around production of DRI from iron ore have been successfully achieved and reported from this Institute by employing Microwave Hydrogen Plasma Reactor process using hydrogen as reductant at a low temperature of 600-800°C. In the present study, similar process has been employed for production of DRI from Red Mud using the same Reactor. The DRI produced in the process has been characterized through mineralogical and chemical analysis. The by-product "water" produced in the process can be recycled when the process is carried out in a commercial scale.

Keywords: Red mud 1, microwave hydrogen plasma reactor 2 , green direct reduced iron 3, water 4.

1. Introduction

Red Mud of Indian origin contains around 55% plus of Fe_2O_3 and is considered as a hazardous waste material for the alumina industry which is generated in the order of two tones of Red Mud per one tone of alumina produced from bauxite. The worldwide alumina production is around 58 million tonnes in which India counts for 2.7 million tonnes. India produces around 5.4 million tonnes of Red Mud per annum from its various alumina refineries.

Major players in the Indian aluminium sector are INDAL, BALCO, HINDALCO, NALCO,MALCO, and Vedanta Alumina Ltd. Application of Red Mud for production of different value added items like Portland cement [1, 2], bricks & blocks, tiles, paints &

pigments, soil amending agents, fibre reinforced polymer composites for building materials as wood substitutes [3] etc., have been tried out by many researchers throughout the world. However these applications have resulted in partial utilization of Red Mud and bulk utilization of Red Mud still remains as a challenge before the global aluminium community. Since iron constitutes as a major ingredient of Red Mud amounting to around 53.6%, the scope of its recovery for production of DRIis considered as a scientific& technological challenge. Efforts have been made for production of pig iron from NALCO Red Mud by application of plasma smelting technology[4].Since the processes so far developed for production of pig iron employing Plasma Smelting Technology was not devoid of environmental pollution, the efforts were directed for production of Green DRI by using Microwave Hydrogen Plasma Reactor, considered as a novel and state- of -the - art technology and more so free from environmental hazards. The only by-product that is produced in the process is 'water' which can be recycled for meeting process requirements during scale up of the operation. The process is novel and unique in character and is 100% eco-friendly.

2. Raw Materials

The raw material used for the process was the Red Mud of Indian origin having the following chemical compositions as given in Table 1. The other raw material used for the study was hydrogen gas with 99.9% purity.

Table 1: Typical Composition of Indian Red Mud

Input Material	Fe_2O_3 (%)	SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)	Na_2O (%)	MgO (%)	CaO (%)	LOI (%)
Indian Red Mud	53.6	18.9	2.20	4.88	8.29	0.21	0.54	9.30

3. Experimental

The Red Mud of Indian Origin was subjected to crushing and grinding to bring the size up to -100 mesh which was then pelletized to $40X10^{-3}$m diameter and $3X10^{-3}$m height using an electrically operated automatic briquetting press by addition of 1-2% of water with respect to the amount of sample taken for the study. This was then dried in the oven at 100°C for 2hrs. The dried pellet was then subjected to Hydrogen Plasma Reduction in Microwave Hydrogen Plasma Reactor. The experimental parameters like Flow of Hydrogen, Reduction Temperature, Reduction Time, Pressure, and the Power input were studied for the reduction of iron content in Red Mud for production of Green DRI. The raw materials and the products were analysed for their chemical compositions and mineralogical characters. The reduction studies were carried out as per the process flow sheet given in Figure 1.

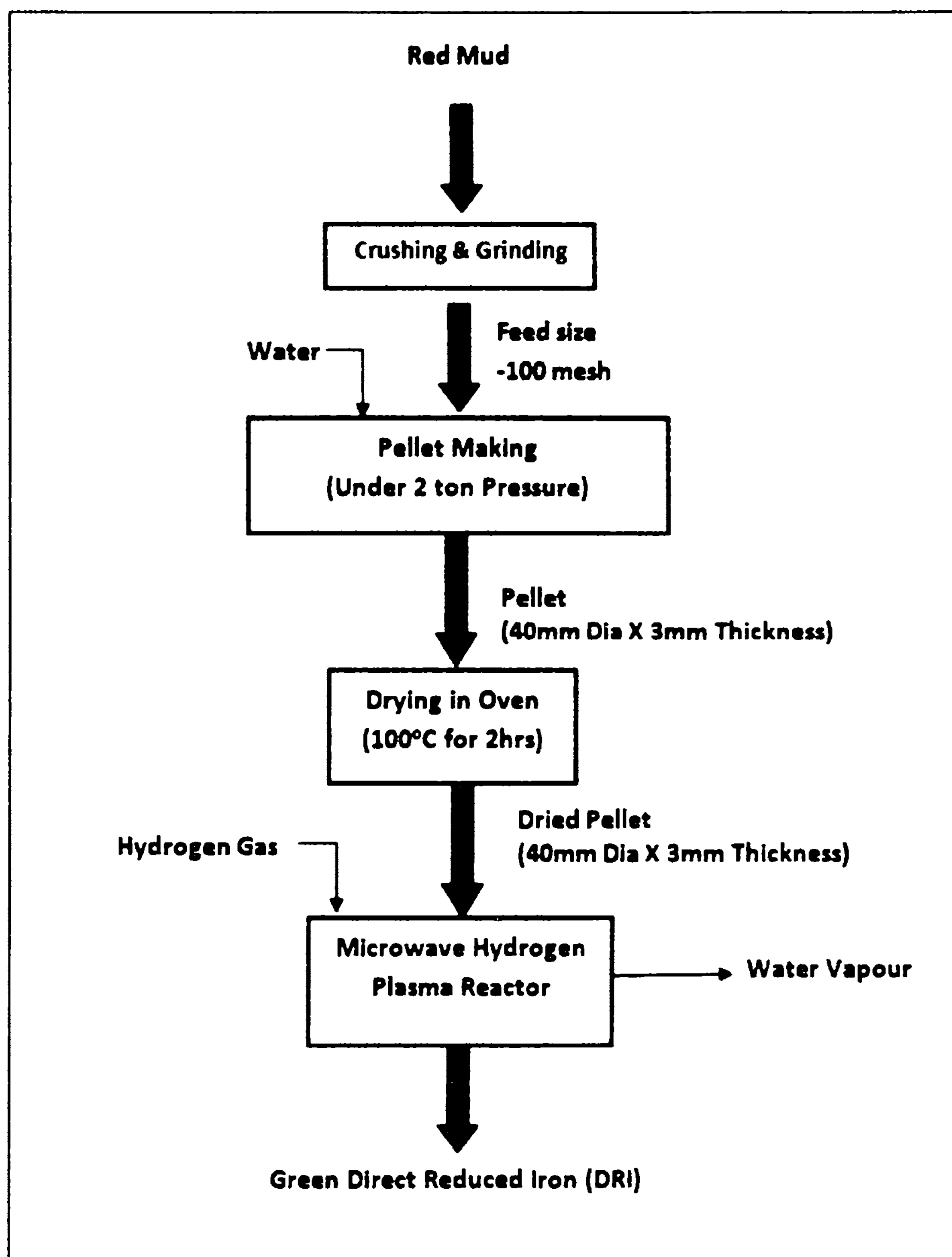


Figure 1: Process Flow Sheet for the Production of Green Direct Reduced Iron (DRI)from Red Mud

3.1 Microwave Hydrogen Plasma Reduction Process

The reduction of raw Red Mud pellet was carried out in a specially built Microwave Hydrogen Plasma Reactor of 6kW power for production of Green DRI. The plasma is generated by Microwave assisted thermal plasma process. The Schematic Diagram of Microwave Hydrogen Plasma Reactor with in-situ photograph of Reactor Chamber is shown in Figure 2. The system has provision to inject Hydrogen gas from the top into the chamber through a safety valve and the flow of the gas can be controlled by a mass flow controller. The temperature of the Molybdenum sample holder is measured by means of an IR Pyrometer. The microwave power can be varied to generate the plasma over a range of temperature. The high frequency waves interact with the hydrogen gas to produce the hydrogen plasma. The plasma produced in this manner covers a region up to about $6X\ 10^{-2}$ to $8\ X\ 10^{-2}$ m above the sample. The hydrogen molecules enter the plasma zone and become part of it. The hydrogen molecules under the influence of plasma dissociate in to atomic and ionic forms which reduces the iron oxide present on the surface of Red Mud pellet into metallic iron. These ionic charged particles of hydrogen recombine immediately in to hydrogen molecules when they exit from the plasma zone.

In all the experiments, samples were kept on a Molybdenum sample holder, and the sample holder was in turn placed at the centre of the reactor chamber. Since the rector chamber is water cooled, the outer surface of the chamber remains at room temperature during the experiments. The extent of reduction with variation in process parameters, such as microwave power, hydrogen flow rate, pressure, temperature and time, was recorded by noting the loss in weight of the pellet. After each experiment, the reduced Red Mud pellet sample as shown in Figure 3 was ground and mixed well, and then a representative sample was taken for analysis. An X'Pert PRO-PAN analytical model No. 3040160 was used for X-Ray Diffraction (XRD) studies of the phases in the reduced Red Mud pellet. The quantitative estimation of the phases was done by using the wet chemical analysis procedure for the total iron, metallic iron, ferrous iron, silica and alumina. The Table 2 describes the chemical analysis result of the reduced red mud pellet.

Table 2: Chemical Analysis of Reduced Red Mud Pellet

Input Material	Fe(T) (%)	Fe(M) (%)	FeO (%)	SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)
Reduced Red Mud Pellet	87.89	77.95	12.00	7.89	2.44	1.78

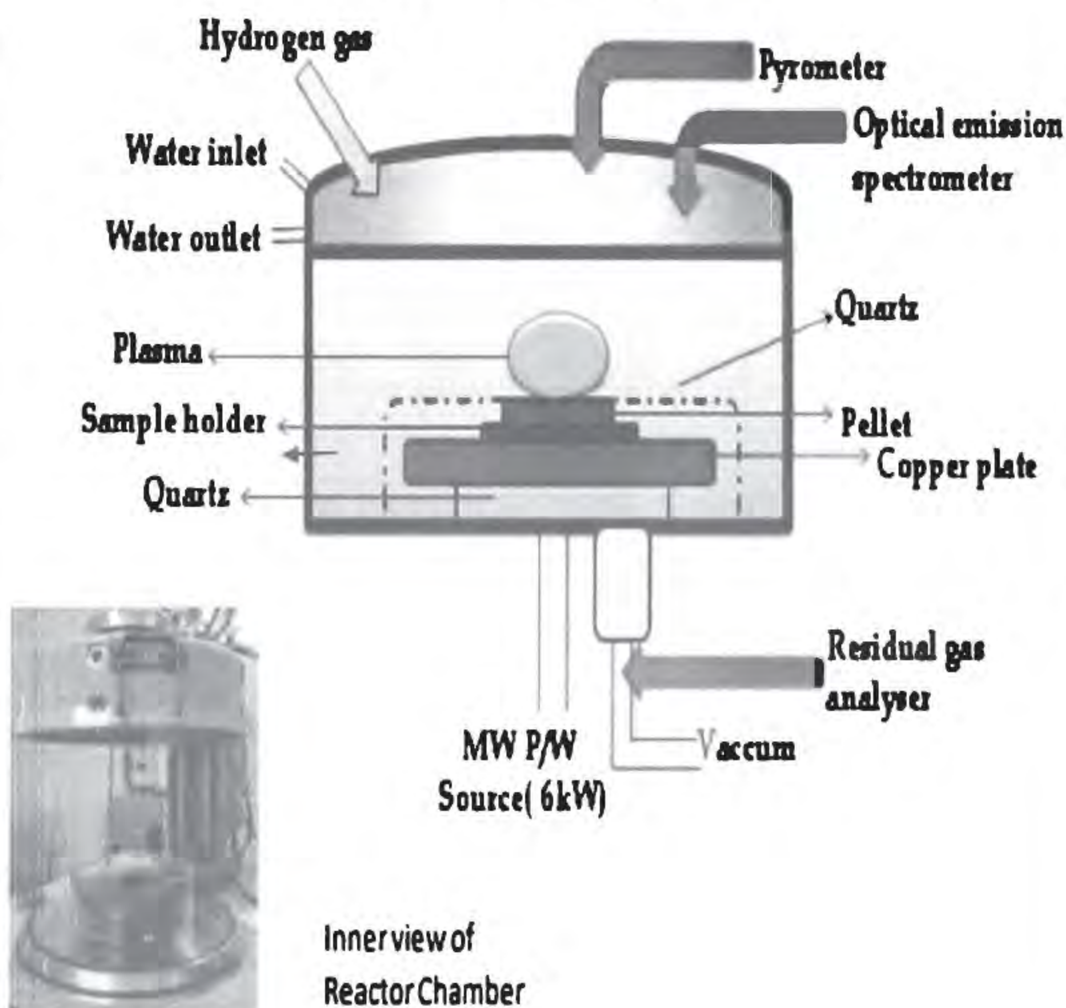


Figure 2: Schematic Diagram of Microwave Hydrogen Plasma Reactor with in-situ photograph of Reactor Chamber

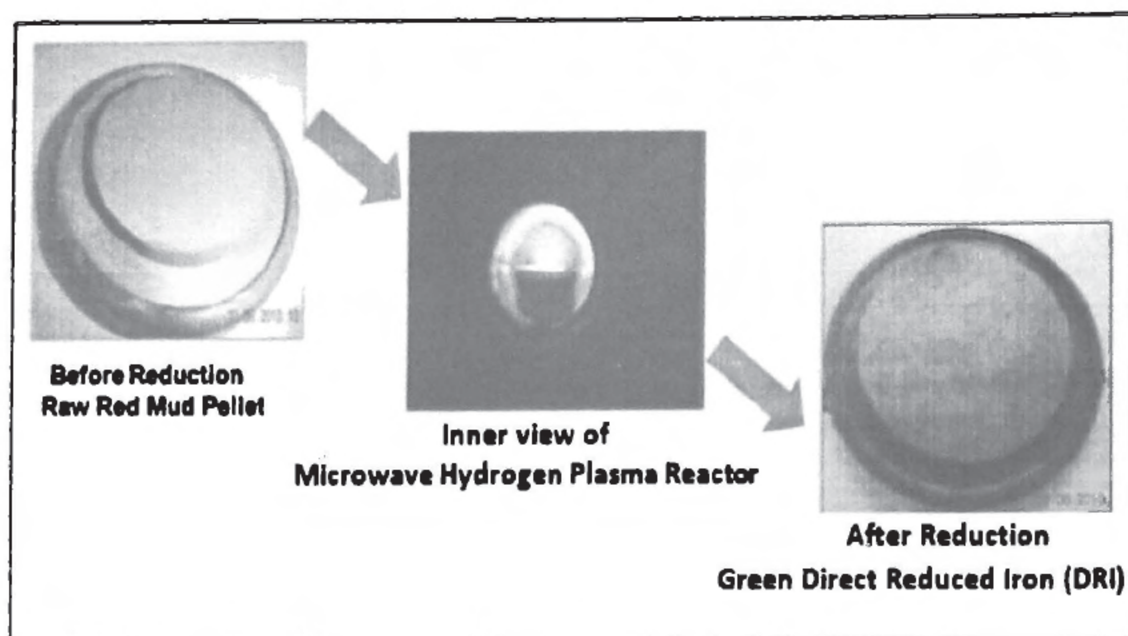
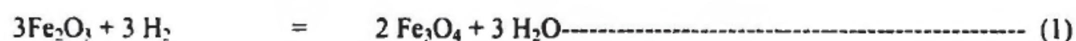


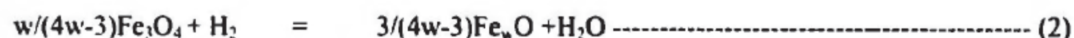
Figure 3: Microwave Hydrogen Plasma Reduction of Raw Red Mud pellet for production of Green Direct Reduced Iron (DRI)

4. Results and Discussions

There is no doubt that hydrogen can be used as a reducing gas in direct reduction processes. A careful analysis of the literature shows that iron oxides can be reduced by hydrogen gas and in this contest, a series of relevant reactions are as follows:



$3Fe_2O_3 + 3H_2 = 2Fe_3O_4 + 3H_2O$ ---------- (1)



$w/(4w-3)Fe_3O_4 + H_2 = 3/(4w-3)Fe_wO + H_2O$ ---------- (2)



$Fe_wO + H_2 = wFe + H_2O$ ---------- (3)



$Fe_3O_4 + 4H_2 = 3Fe + 4H_2O$ ---------- (4)



$2H_2 + O_2 = 2H_2O$ ---------- (5)



$2Fe + O_2 = 2FeO$ ---------- (6)



$4H + O_2 = 2H_2O$ ---------- (7)



$4H^{+} + 2O^{2-} = 2H_2O$ ---------- (8)

It has been shown that molecular hydrogen is a good reductant for iron oxides, which follows the reactions (1)-(3). In these reactions, w is the atomic ratio of iron to oxygen in wüstite and is known to vary from 0.95 along the wüstite-iron boundary to 0.85 along the wüstite-magnetite boundary. Bellow 833K wüstite is unstable and hence magnetite is reduced directly to metallic iron as per reaction (4). It is also known that reactions (2) & (3) are endothermic at any temperature, where as reaction (1) is weakly endothermic in the temperature range 827- 913K and exothermic at other temperatures. Figure 4 presents the Ellingham-Richardson- Diagram showing the reducing potential of hydrogen (5) in comparison to other reactions, is transformation of FeO to Fe as shown in reaction (6). As seen from Figure 4, molecular hydrogen reduced Fe_2O_3 and Fe_3O_4 quite easily, though ΔG^ovalues for reactions (5) & (6) are much closer. However, it is also seen from the Figure3 that ΔG^o values for reactions (7) & (8), involving atomic and ionic hydrogen species respectively, are very high and negative in comparison to reaction (5), which involves molecular hydrogen. The two species H and H^+ are provided by the plasma. In other words, in the plasma state, both H and H^+ can coexist. In hydrogen plasma smelting reduction process, these plasma states of hydrogen do also exist for production of iron[5 –10].

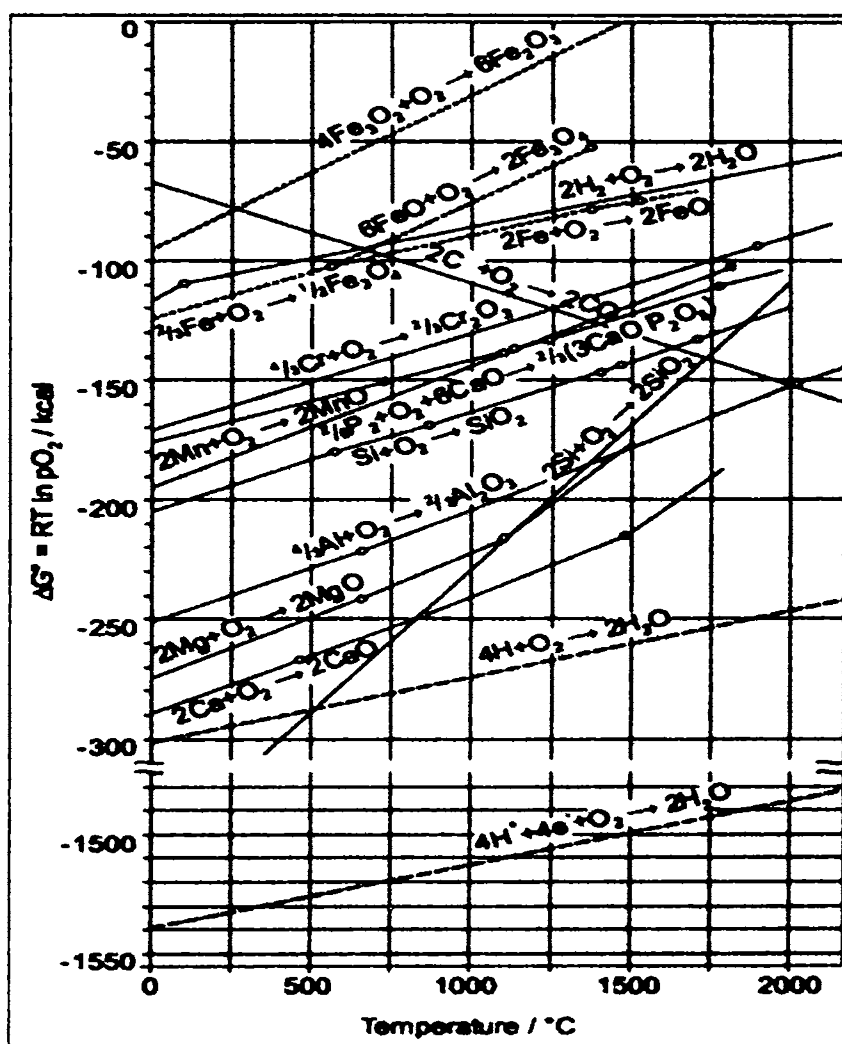


Figure 4: Ellingham-Richardson- Diagram

Keeping these in view, efforts were directed for production of Green DRI from the Red Mud of Indian origin which contains good amount of iron oxide using Microwave Hydrogen Plasma Reactor. Experiments were conducted to ascertain the possibility of reduction of iron oxide present in Red Mud in to iron using various experimental parameters. The results were shown in Table 2.

4.1 Effect of Time

The hydrogen gas starts reacting with the iron oxide present in the Red Mud Pellet from the surface itself and gradually it penetrates inside the body of the pellet for which reduction time plays an important role. The experiments were carried out at various reduction time intervals keeping other parameters constant as shown in Table 3. From Table 3, it is observed that the percentage reduction of iron oxide present in Red Mud Pellet into iron increases with increase in time and at 120minutes, it becomes 98.23 % and that too at a low temperature of 300°C. Further, the XRD results at Figure 5 indicate that how over the passage of time, the iron peaks gets prominence and its presence is established.

Table 3: Reduction of compacted Red Mud Pellet by Microwave Hydrogen Plasma at various time intervals (Temperature: 300°C, Microwave Power: 750W, Pressure: 5.33 X 10^3 Pa, Hydrogen Flow Rate: 3.33 x 10^{-6} m^3s^{-1})

Sl.No	Time (min)	Initial weight (g)	Final weight (g)	Reduction (%)
1	15	15.023	14.170	20.18
2	30	15.015	13.150	45.69
3	45	14.910	12.460	64.30
4	60	14.910	12.210	70.56
5	120	14.920	11.210	98.23

4.2 Effect of Temperature

As seen in Table 3, even at a low Temperature of 300°C, a percentage reduction of 98.23 was achieved at a time interval of two hours duration. Accordingly, further experiments were carried out to see both the effect of temperature and time on percentage reduction of iron oxide present in Red Mud pellet. The results obtained from these studies are shown in Table 4 , which indicates that percentage of reduction of iron oxide present in Red Mud Pellet increases from 70.56 to 99.3 with increase in temperature from 300 to 800°C keeping reduction time 60 minutes as constant. From the results of Table 3 and Table 4, it can be derived that percentage reduction of iron oxide is faster at a higher temperature (800°C) than at 300°C. It may be because of the fact that more and more of excited hydrogen species are taking part in the reduction process as temperature gradually increases. The XRD results indicate the prominence of iron peaks with variation in temperature (Figure 6).

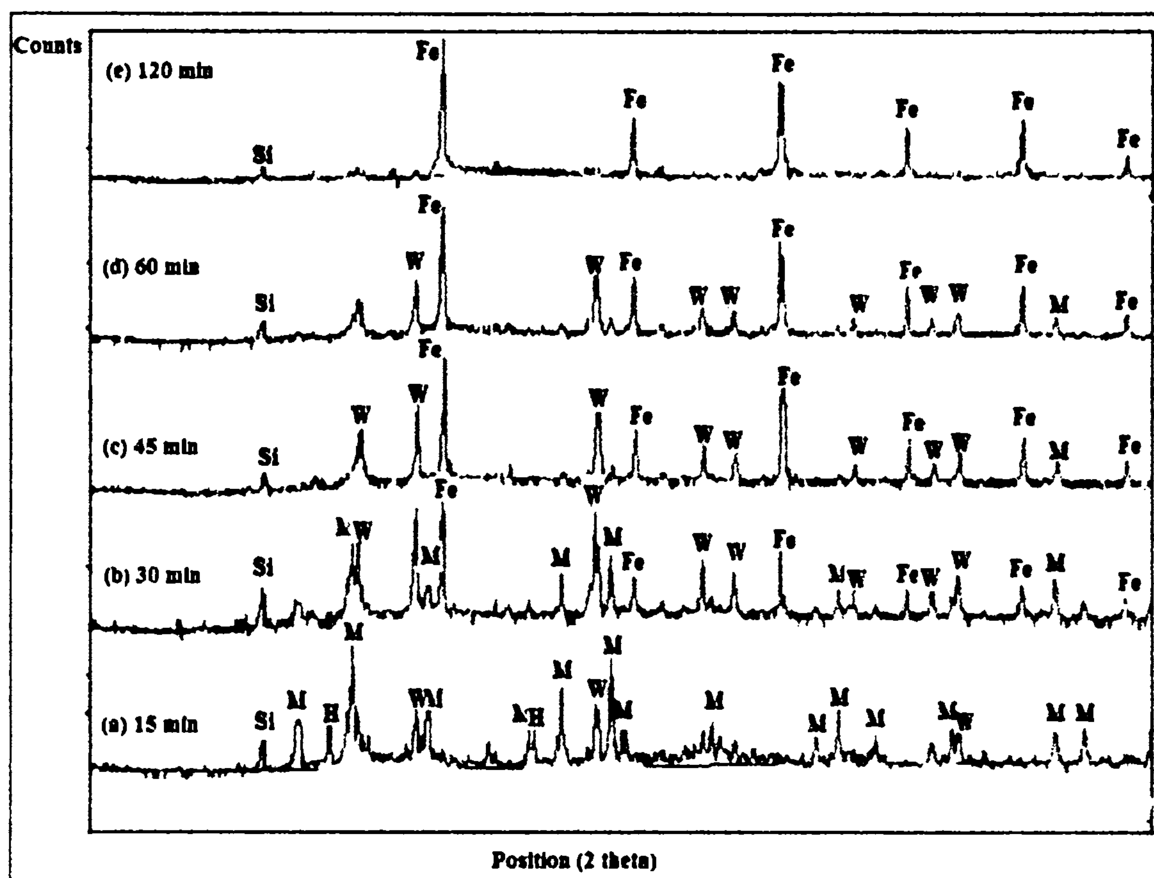


Figure 5: XRD Diffraction plots for Red Mud Pellet reduced by Microwave Hydrogen Plasma at various time intervals

Table 4: Reduction of compacted Red Mud Pellet by Microwave Hydrogen Plasma at various Temperatures (Time: 60 min, Microwave Power: 750W, Pressure: 6.66 X 10^3 Pa, Hydrogen Flow Rate: 3.33 x 10^{-6} m^3s^{-1})

Sl.No	Temperature (°C)	Initial weight (g)	Final weight (g)	Reduction (%)
1	300	15.023	14.170	70.56
2	450	15.015	13.150	89.7
3	600	14.910	12.460	91.6
4	800	14.910	12.210	99.3

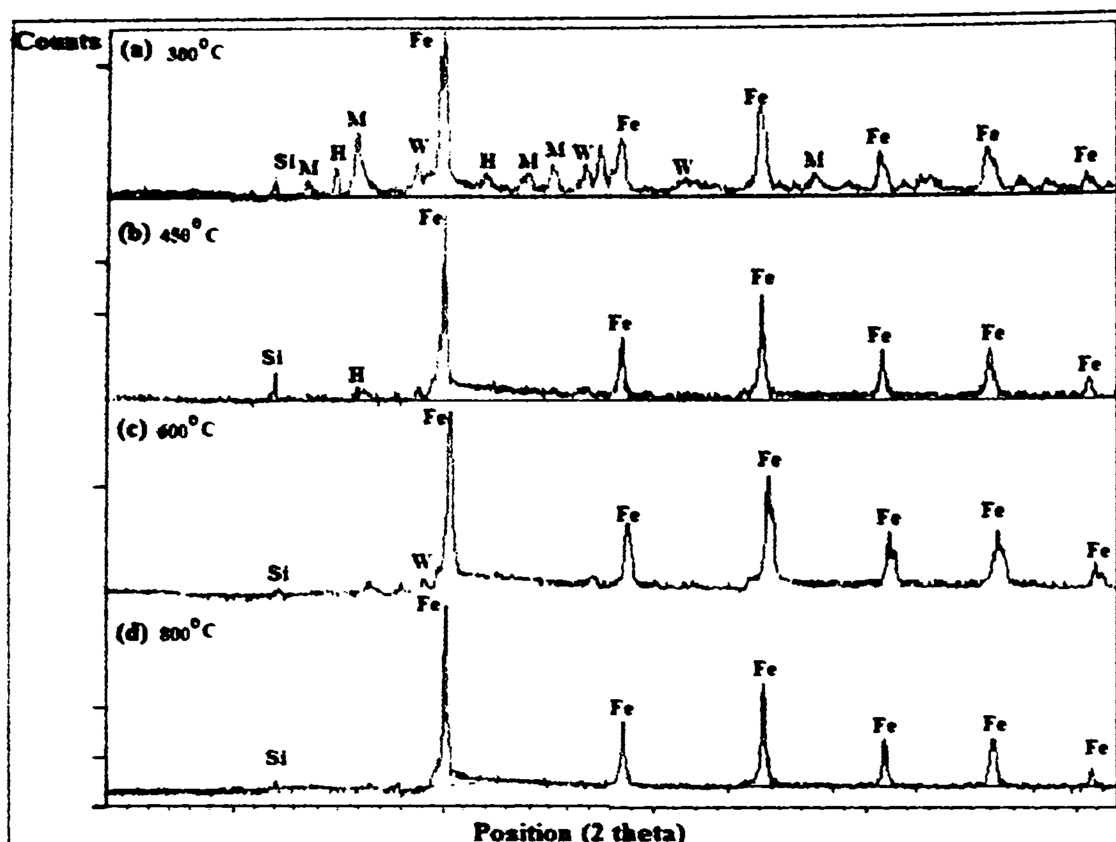


Figure 6: XRD Diffraction plots for Red Mud Pellet reduced by Microwave Hydrogen Plasma at various temperatures

5 Eco-friendly Process

The conventional process of iron making through DRI route has limitations. It requires higher temperature of around 1200°C to convert iron oxide in to metallic iron. In the other hand, the present process needs low temperature of around 300°C only to carry out the reduction and is more energy and cost effective. Furthermore, the process is green in character as it is carbon free and environmental friendly and generates 'water' in the process as a by-product which can be recycled when used in the commercial process.

6 Conclusion

From the above experimental evidences and observations, it can be concluded that Red Mud containing around 53.6% Fe_2O_3 and some appreciable quantities of Al_2O_3 and other associated metal oxides in minor quantities, can very well be reduced to Green DRI by application of Microwave Hydrogen Plasma technology. The process has been successfully established in the laboratory scale and needs to be scaled up to pilot scale of operation before its commercial feasibility is established. CSIR-IMMT, Bhubaneswar, Odisha, India is in possession of laboratory scale technology for production of Green DRI from Red Mud of Indian origin and the know-how is readily available for commercial exploitation.

7 Acknowledgement

The authors are grateful to Prof. (Dr.) B. K.Mishra, Director, CSIR-IMMT, Bhubaneswar for his cooperation and guidance in the R&D work and giving permission for publication of the paper. The authors are also grateful to the Indian aluminium industries for providing Red Mud samples for carrying out the investigation.

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- *Source: Natural Resources Development Foundation (NRDF) International Symposium held at Bhubaneswar during September 23-25, 2015, Technical Proceedings, pp 158-168.*

Processing of red mud by low temperature microwave hydrogen plasma for production of iron: An eco-friendly technology

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Abstract

Red mud is produced in huge quantities during the processing of bauxite for the production of alumina. So far, few economically attractive processes have been developed for bulk utilization of red mud. Researchers are trying to develop interesting processes and products from this waste material; success achieved so far is restricted to laboratory, pilot scale, isolated or minor volume utilization applications and processes. Red mud of Indian origin contains around 45 – 55 % Fe_2O_3, 11 % TiO_2, 20 % Al_2O_3, 9 % SiO_2 and other associated oxides in minor quantities. Iron being the major component, bulk utilization of red mud will be difficult without an economically and technically viable process being developed for the production of iron from red mud. Indian iron ore containing 45 % Fe_2O_3 is considered as the cut-off grade for the economic production of iron. Accordingly, red mud of Indian origin can be considered as a low grade iron ore. The present study examines the processing of Indian red mud by Low Temperature Hydrogen Plasma for the production of iron in eco-friendly manner at laboratory scale. The iron produced contains 95 % Fe with low carbon and sulphur. Water, which can be recycled, is produced as a by-product of the process.

Key words: Red mud; hydrogen reduction; microwave hydrogen plasma reactor; iron from red mud.

1 Introduction

Red mud is a byproduct generated during the processing of bauxite with caustic soda utilizing the Bayer process. It is considered as a hazardous material and till today few economically interesting applications or processes have been developed for its bulk utilization. Researchers have tried to produce pig iron from red mud by the application of plasma smelting technology [1], production of pig iron and portland slag cement from red mud by application of novel thermal plasma technique [2], production of ordinary Portland cement (OPC) from red mud [3], and processing of red mud for the production of wood substitute materials [4]. All efforts in this direction have so far been restricted either to laboratory or pilot scale processes. Iron oxide is a major constituent of red mud and for this reason it can very well be considered as a low grade iron ore. Red mud of Indian origin contains around 45 – 55 % Fe_2O_3, 11 % TiO_2, 20 % Al_2O_3, 9 % SiO_2 and other associated oxides in minor quantities. The quantum of generation of red mud by the alumina industries all over the globe warrants its gainful utilization in bulk quantities. An important option available presenting to researchers is extraction of iron from red mud in a most eco-friendly manner.

The reduction of Fe_2O_3 present in red mud to metallic iron can be achieved either by carbothermic or hydrogen reduction processes. The carbothermic reduction process involves a blast furnace route

for production. However, this process is not free from pollution and emits large quantities of carbonaceous gases which add to global warming. It has been estimated that for production of one tone of iron, around three tones of green house gases are generated. Under the circumstances, industry have few other alternatives but to follow an eco-friendly (and lower energy cost) path way for production of iron through a hydrogen reduction process. Researchers elsewhere have tried to produce metallic iron from iron ore employing the hydrogen reduction process by using hydrogen gas as reductant in a high temperature furnace [5]. This process has limitations, such as it being a time consuming process associated with low yield and moreover, consumption of hydrogen gas was also increased.

The answer to this challenge lies with the state-of-the-art technology for production of metallic iron from iron ores by application of the low temperature Microwave Hydrogen Plasma Reduction route. Through this route, iron was extracted successfully from iron ores as Direct Reduced Iron [6].

Once researchers successfully accomplished such an eco-friendly reduction process, the process know- how was then suitably replicated for production of iron from red mud through application of a Low Temperature Microwave Hydrogen Plasma Reduction Process using hydrogen gas as a reductant. The product so obtained contains 95% Fe with low carbon and sulphur. The process is eco-friendly and free from carbon. Moreover, 'water' is generated in the process as a by-product which can be recycled when commercially used.

2 Raw Materials

The red mud of Indian origin was used as principal raw material for the study. The mineralogical composition and chemical analysis of red mud are furnished in Figure 1 and Table 1 respectively. The other raw materials used for the study were hydrogen gas of 99.9% purity and argon gas.

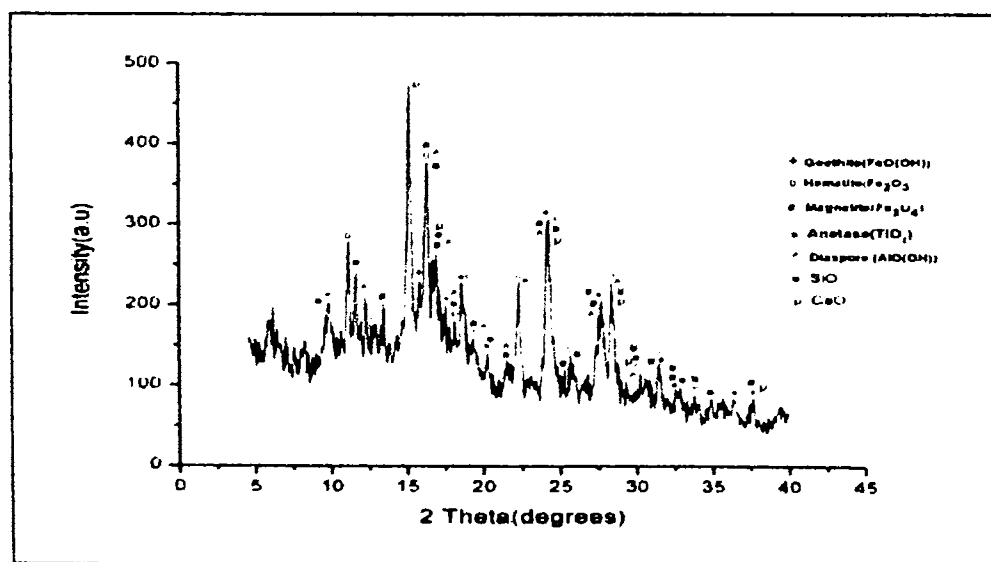


Figure1. Mineralogical composition of red mud of Indian origin.

Table 1. Typical chemical analysis of Indian red mud.

Input material	Fe_2O_3	SiO_2	TiO_2	Al_2O_3	Na_2O	MgO	CaO	LOI
Indian red mud	53.6	18.9	2.20	4.88	8.29	0.21	0.54	9.30

3 Experimental

A red mud sample was subjected to crushing and grinding to bring the size to -100 mesh which was then pelletized to 40 mm diameter and 3 mm height using an electrically operated automatic briquetting press by addition of 1 – 2 % of water with respect to the amount of sample taken for the study. This was then dried in the oven at 100 °C for 2 hours. The dried pellet was then subjected to Hydrogen Plasma Reduction in Microwave Hydrogen Plasma Reactor. The experimental parameters like flow of hydrogen, reduction temperature, reduction time, pressure, and the power input were studied for the reduction of the iron content in red mud to produce direct reduced iron (DRI). The raw materials and the products were analyzed for their chemical compositions and mineralogical characters. The reduction studies were carried out as per the process flow sheet given in Figure 2.

3.1 Microwave Hydrogen Plasma Reduction Process

The reduction of the raw red mud pellet to produce DRI was carried out in a specially built Microwave Hydrogen Plasma Reactor of 6 kW power. The plasma is generated by microwave assisted thermal plasma process. The schematic diagram of Microwave Hydrogen Plasma Reactor with in-situ photograph of the reactor chamber is shown in Figure 3. The system has provision to inject hydrogen gas from the top into the chamber through a safety valve and the flow of the gas can be controlled by a mass flow controller.

The temperature of the molybdenum sample holder is measured by means of an infrared (IR) pyrometer. The microwave power can be varied to generate the plasma over a range of temperatures. The high frequency waves interact with the hydrogen gas to produce the hydrogen plasma. The plasma produced in this manner covers a region up to about 6 to 8 cm above the sample. The hydrogen molecules enter the plasma zone and become part of it. The hydrogen molecules under the influence of plasma dissociate in to atomic and ionic forms which reduces the iron oxide present on the surface of red mud pellet into metallic iron. These ionic charged particles of hydrogen return immediately to hydrogen molecules when they exit from the plasma zone.

In all the experiments, samples were kept on a molybdenum sample holder, and the sample holder was in turn placed at the centre of the reactor chamber. Since the rector chamber is water cooled, the outer surface of the chamber remains at room temperature during the experiments. The extent of reduction with the variation in process parameters, such as microwave power, hydrogen flow rate, pressure, temperature and time, was recorded by noting the loss in weight of the pellet. After each experiment, the reduced red mud pellet sample was ground and mixed well, and then a representative sample was taken for analysis. An X'Pert PRO-PAN analytical model No. 3040160 was used for X-Ray Diffraction (XRD) studies of the phases in the reduced red mud pellet. The quantitative estimation of the phases was done by using the wet chemical analysis procedure for the total iron, metallic iron, ferrous iron, silica and alumina. Table 2 describes the chemical analysis of the reduced red mud pellet. The schematic diagram of the process know how employed is given in Figure 2.

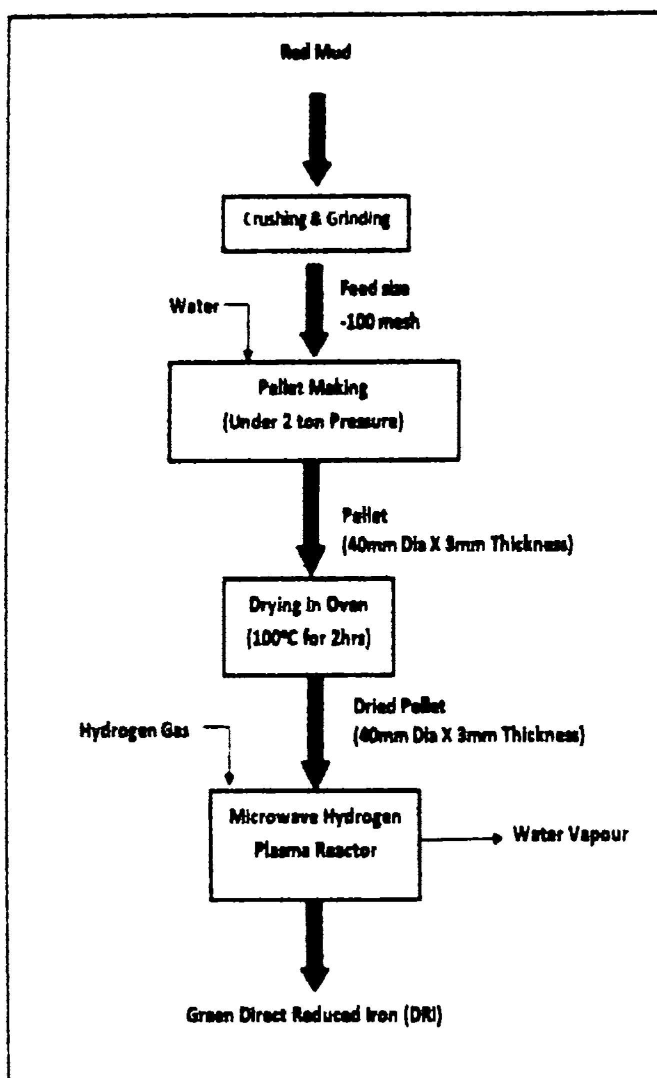


Figure 2. Process flow sheet for the production of green direct reduced iron (DRI) from red mud.

Table 2. Chemical analysis of reduced red mud pellet.

Input material	Fe(T) (%)	Fe(M) (%)	FeO (%)	SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)
Reduced red mud pellet	87.89	77.95	12.00	7.89	2.44	1.78

Schematic: Microwave Hydrogen Plasma Reactor

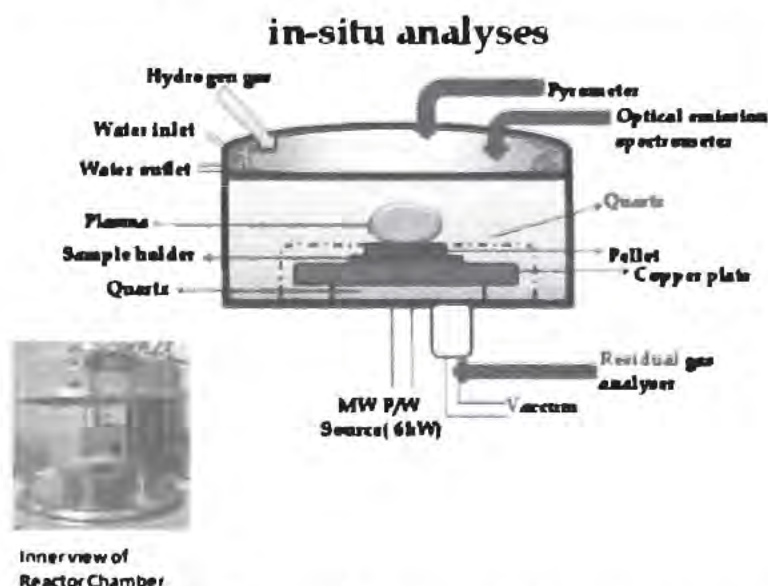
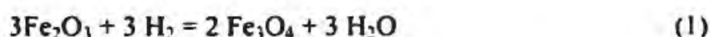


Figure 3. Schematic diagram of microwave hydrogen plasma reactor

4 Results and discussions

There is no doubt that hydrogen can be used as a reducing gas in direct reduction processes. A careful analysis of the literature shows that iron oxides can be reduced by hydrogen gas and in this contest, a series of relevant reactions are as follows:



$$3Fe_2O_3 + 3\ H_2 = 2\ Fe_3O_4 + 3\ H_2O \quad (1)$$



$$w/(4w\text{-}3)Fe_3O_4 + H_2 = 3/(4w\text{-}3)Fe_wO + H_2O \quad (2)$$



$$Fe_wO + H_2 = w\ Fe + H_2O \quad (3)$$



$$Fe_3O_4 + 4\ H_2 = 3Fe + 4\ H_2O \quad (4)$$



$$2H_2 + O_2 = 2H_2O \quad (5)$$



$$2Fe + O_2 = 2FeO \quad (6)$$



$$4H + O_2 = 2H_2O \quad (7)$$



$$4H^{-} + 2O^{2-} = 2H_2O \quad (8)$$

It has been shown that molecular hydrogen is a good reductant for iron oxides, which follows the reactions (1) - (3). In these reactions, w is the atomic ratio of iron to oxygen in wüstite and is

known to vary from 0.95 along the wüstite-iron boundary to 0.85 along the wüstite-magnetite boundary. Below 833 K wüstite is unstable and hence magnetite is reduced directly to metallic iron as per reaction (4). It is also known that reactions (2) and (3) are endothermic at any temperature, where as reaction (1) is weakly endothermic in the temperature range 827- 913 K and exothermic at other temperatures.

Figure 4 presents the Ellingham-Richardson Diagram showing the reducing potential of hydrogen (5) in comparison to other reactions, its transformation of FeO to Fe as shown in reaction (6). As seen from Figure 4, molecular hydrogen reduces Fe_2O_3 and Fe_3O_4 quite easily, though ΔG^0 values for reactions (5) & (6) are much closer. However, it is also seen from the Figure 3 that ΔG^0 values for reactions (7) & (8), involving atomic and ionic hydrogen species respectively, are very high and negative in comparison to reaction (5), which involves molecular hydrogen. The two species H and H^- are provided by the plasma. In other words, in the plasma state, both H and H^+ can coexist. In the hydrogen plasma smelting reduction process, these hydrogen plasma states do also exist for production of iron [7 - 9]. Keeping these in view, efforts were directed at the production of iron from the red mud of Indian origin using the Microwave Hydrogen Plasma Reactor, using various experimental parameters. The results were shown in Table 2.

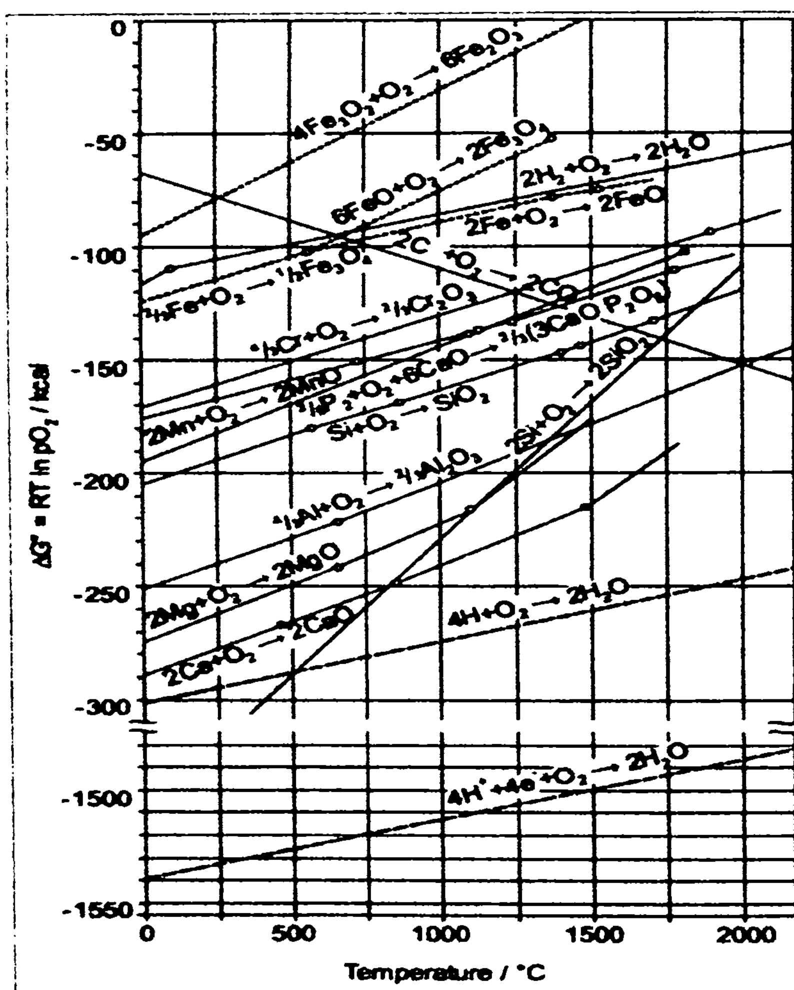


Figure 4. Ellingham-Richardson- Diagram.

4.1 Effect of time

The hydrogen gas starts reacting with the iron oxide present in the red mud pellet from the surface and gradually penetrates the body of the pellet for which reduction time plays an important role. The experiments were carried out at various reduction time intervals keeping other parameters constant as shown in Table 3. From this table, it is observed that the percentage reduction of iron oxide to iron present in red mud pellet increases with increasing time. At 120 minutes, reduction is 98.23 %, and that at a low temperature of 300 °C. The XRD results in Figure 5 indicate that over time, the iron peaks become prominent, and its presence is established.

Table 3. Reduction of compacted red mud pellet by Microwave Hydrogen Plasma at various time intervals (temperature: 300 °C, microwave power: 750 W, pressure: 5.33 kPa, hydrogen flow rate: 3.33 mL/s).

Sl.No	Time (min)	Initial weight (g)	Final weight (g)	Reduction (%)
1	15	15.023	14.170	20.18
2	30	15.015	13.150	45.69
3	45	14.910	12.460	64.30
4	60	14.910	12.210	70.56
5	120	14.920	11.210	98.23

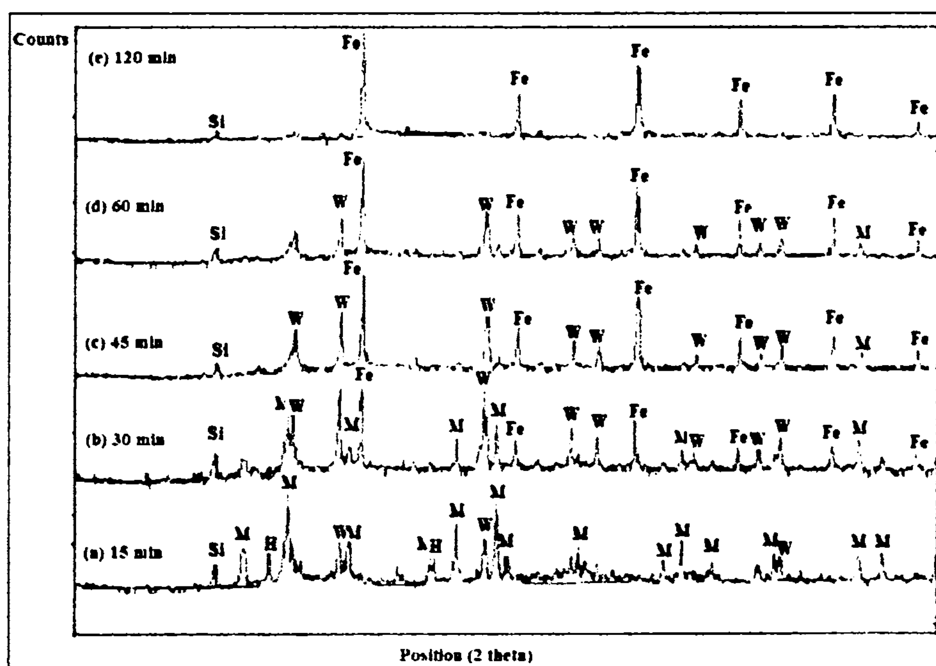


Figure 5. XRD Diffraction plots for red mud pellet reduced by Microwave Hydrogen Plasma at various time intervals.

4.2 Effect of temperature

As seen in Table 3, even at a low Temperature of 300 °C, a percentage reduction of 98.23 was achieved at a time interval of two hours duration. Accordingly, further experiments were carried out to see both the effect of temperature and time on percentage reduction of iron oxide present in the red mud pellet. The results obtained from these studies are shown in Table 4 , which indicates that the percentage reduction in the pellet increases from 70.56 to 99.3 with increase in temperature from 300 to 800 °C, keeping reduction time a constant 60 minutes. From the results of Tables 3 and 4, it can be concluded that the percentage reduction of iron oxide is faster at a higher temperature (800 °C) than at 300 °C. It may be because of the fact that more and more of excited hydrogen species are taking part in the reduction process as temperature gradually increases. The XRD results indicate the prominence of iron peaks with variation in temperature (Figure 6).

Table 4. Reduction of compacted red mud pellet by microwave hydrogen plasma at various temperatures (time: 60 min, microwave power: 750 W, pressure: 6.66 kPa, hydrogen flow rate: 3.33 mL/s).

Sl.No	Temperature (°C)	Initial weight (g)	Final weight (g)	Reduction (%)
1	300	15.023	14.170	70.56
2	450	15.015	13.150	89.7
3	600	14.910	12.460	91.6
4	800	14.910	12.210	99.3

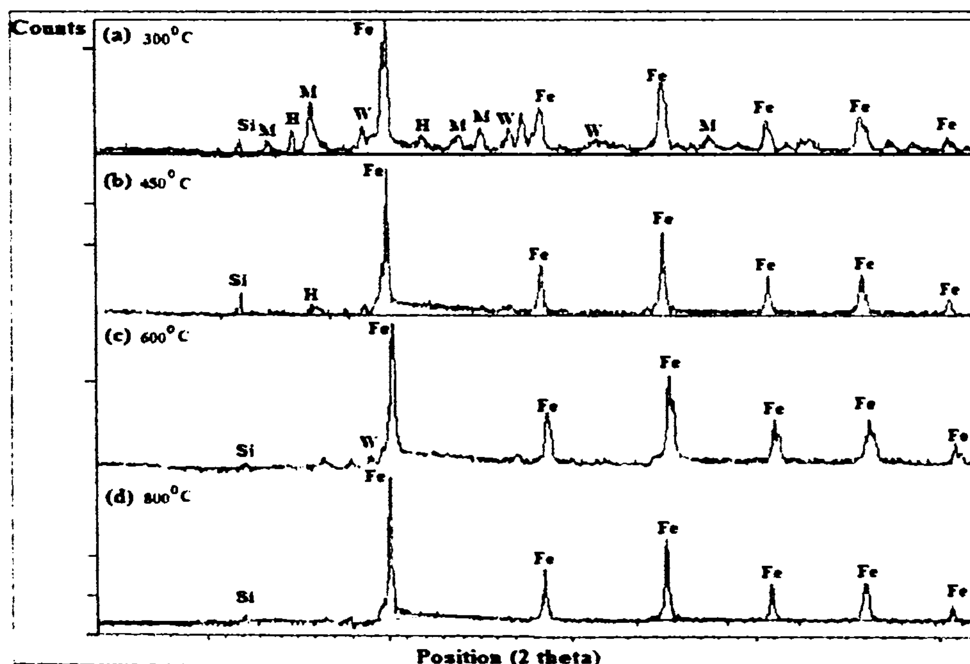


Figure 6. XRD Diffraction plots for red mud pellet reduced by Microwave Hydrogen Plasma at various temperatures.

4.3 Reaction mechanism at the surface of the red mud pellet

In the Microwave Hydrogen Plasma Reactor, the hydrogen gas passes from the top of the reactor through the plasma zone and comes in contact with the surface of the red mud pellet. At the surface of the pellet, the gas-solid reaction takes place. Figure 7 indicates the path way of the reaction mechanism from raw red mud pellet to iron. In the context of gas-solid reaction, in addition to ionic and atomic species of hydrogen, the role of vibrationally excited hydrogen molecules has also been emphasized in the literature [2]. It has been reported that vibrationally excited hydrogen molecules stimulate the chemical process through their surface dissociation and diffusion of hydrogen atoms into the crystal structure of iron oxide present in red mud pellet. The experimental data of P. Rajput et al [2] provide evidence to the presence of vibrationally excited hydrogen molecules. Therefore, similar reaction mechanism may also be happening at the surface of the red mud pellet for the production of iron. Accordingly, it can be concluded that vibrationally excited hydrogen molecules are probably the species responsible for reduction of iron oxide present. Another alternate possibility may be the contribution of the atomic and ionic species of hydrogen plasma as a catalyst to drive reduction of iron oxide in the pellet. However, more studies are required to obtain further insight with respect to reaction mechanism at low temperature.

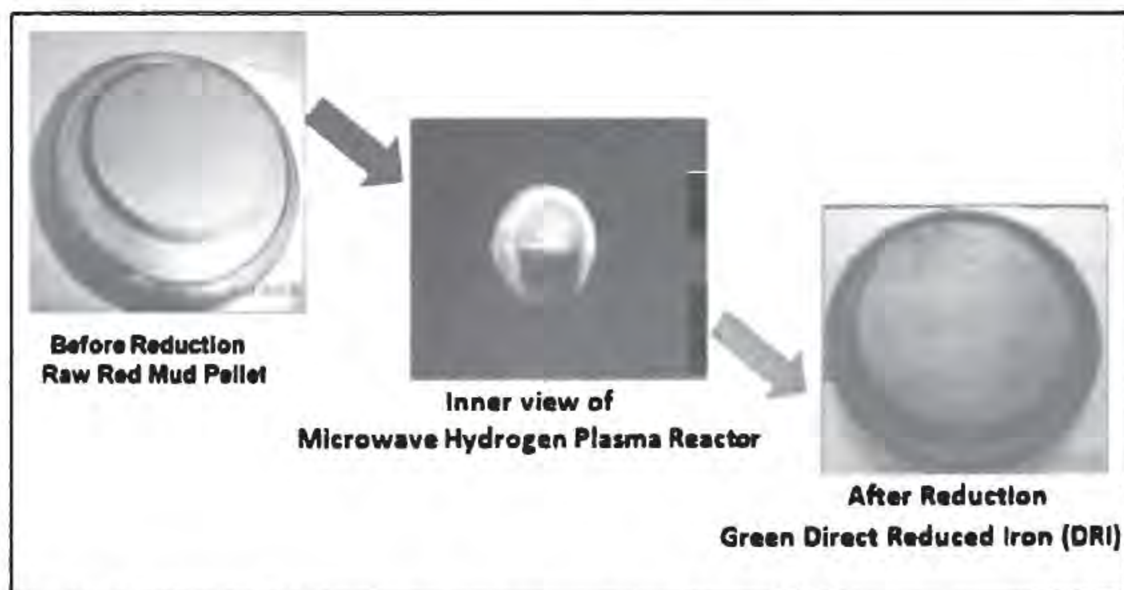


Figure 7. Microwave Hydrogen Plasma reduction of raw red mud pellet for production of Green Direct Reduced Iron (DRI).

5 Eco-friendly process

The conventional process of iron making through DRI route has limitations. It requires a high temperature of around 1200 °C to convert iron oxide in to metallic iron. The process presented here on the other hand, needs only a temperature of around 300 °C to carry out the reduction and is more energy and cost effective. The process is green in character as the central process is carbon free and environmental friendly, and generates 'water' in the process as a by-product which can be recycled when used in the commercial process.

6. Conclusions

From the above experimental evidences and observations, it can be concluded that red mud containing around 53.6 % Fe_2O_3 and some appreciable quantities of Al_2O_3 and other associated metal oxides in minor quantities, can very well be reduced to iron by the application of Microwave Hydrogen Plasma technology.

The process has been successfully demonstrated at laboratory scale, but needs to be demonstrated at pilot scale before its commercial feasibility is established. CSIR-IMMT, Bhubaneswar, Odisha, India is in possession of laboratory scale technology for production of iron from red mud of Indian origin and the know-how is readily available for commercial exploitation.

7 Acknowledgement

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• *Source: ICSOBA-2015 International Conference held at Dubai, Nov. 29 – Dec. 1, 2015, Technical Proceedings, pp 305-314.*

WASTE UTILISATION IN ALUMINIUM INDUSTRY: THE INDIAN PERSPECTIVE

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ABSTRACT

Aluminium Industry generates mainly two types of wastes viz. Red Mud in the Alumina Refinery and Spent Pot Lining Materials (SPL) in the Aluminium Smelter Plant. For carrying out smelting operations, Indian Aluminium Industry fully depends on coal based Thermal Power Plants generating huge quantities of Fly Ash which is pumped in the slurry form in to the nearby Ash Pond for necessary storage & disposal. Around 4.2 million tones of Red Mud are generated by the Alumina Refineries of India which are safely disposed and stored in the nearby Red Mud Pond. Various technological options have been studied for utilization of Red Mud and many Red Mud based value added products/ processes have been developed and patented. Similarly, SPL generated in different Aluminium Smelter Plants of India is stored in concrete pits as per the guidelines stipulated by the Environmental Statutory Authorities. Some SPL based value added products and processes have been successfully developed in the laboratory /pilot plant scale and patented for commercialization. Around 100 million tones of Fly Ash is generated in India per annum from around 300 million tones of Coal consumed in different Thermal Power Plants for generation of around 98,000 MW of Power. Fly Ash have been successfully tried out in many application frontiers for development of different value added products/ processes and its bulk utilization.

Key Words: *Waste Utilization, Aluminium Industry, Red Mud, SPL & Fly Ash*

Introduction:

Bauxite is the buzz word now in Indian mining as the present is being built on it and the future of India will rest on it. And in India we have huge bauxite resources. India's position is 4th in the world after Guinea, Australia and Brazil with a resource of more than 3 billion tones of bauxite, out of the total world reserves of 35 billion tons. Alone, the state of Orissa is bestowed with huge metallurgical grade bauxite resources estimated to be in excess of 2 billion tons. However, the Alumina Production capacity in India is only around 3.5 million tons against world alumina production capacity of approx 85 million tons. Looking into vast bauxite deposits of India, and the ever expanding market for aluminium, a number of National and International companies in the last two decades made consistent efforts to establish Alumina and Aluminium Complex in Orissa and Andhra Pradesh after successful commissioning of NALCO Alumina Refinery at Damanjodi, Orissa in 1986.

The major bauxite deposits in Orissa are located along East Coast belt and most of the deposits are gibbsite in nature and are considered as one of the best deposits in the world.

Experimental:

(A) **Utilization of Red Mud**:
In the Bayer Process of Alumina Refining, for every ton of alumina produced around 1.2 tons of Red Mud is generated which is disposed in the slurry form in the nearby pond made specifically for the purpose. Indian Aluminium Industry produces around 4.2 million tons of Red Mud per annum. NALCO generates 2.033 million tons, BALCO 0.300 million tons, HINDALCO 1.80 million tons and MALCO 0.180 million tons per annum. Typical Chemical Composition of Red Mud is furnished in Table-1.

Table-1 Chemical Composition of NALCO Red Mud:

Constituents	% by Wt.	Constituents	% by Wt.
Al_2O_3	16.13	CaO	01.88
Fe_2O_3	53.92	P_2O_5	00.11
TiO_2	04.82	V_2O_5	00.11
SiO_2	06.29	LOI	11.78
Na_2O	03.45		

Application of Red Mud:
Various application of Red Mud has been attempted with many national and international institutes of repute and considerable success has been achieved in this regard. They are:

(i) Development of Red Mud Cement (Ferrite Cement) in Collaboration with National Council for Cement and Building Materials (NCB), Ballavgarh, Haryana. This process has been patented.
(ii) Development of Red Mud Bricks in Collaboration with Institute of Minerals and Materials Technology (Formerly known as Regional Research Laboratory), Bhubaneswar [1-3].
(iii) Development of Red Mud Fiber Reinforced Polymer Composites for Building Components as Wood Substitute in Collaboration with Advanced Materials and Processes Research Institute (Formerly known as Regional Research Laboratory), Bhopal [4]. This process has been patented.
(iv) Recovery of Iron from Red Mud through Romelt Process in Collaboration with Moscow Institute of Steel and Alloys (MISA), Moscow, Russia.
(v) Study on Effect of Red Mud- Lime Flux Treatment on the Microstructure and Mechanical Properties of Steel in Collaboration with Indian Institute of Technology, Kharagpur West Bengal [5]. This process has been patented.

(B) Utilization of SPL:

The Aluminium Electrolysis Cells are lined with Carbonaceous Materials and have a life of approximately, 5-6 years after which a pot needs to be relined with carbon cathode blocks.

Valuable materials like carbon, soda and fluorine need to be recovered for recycling and putting in to some good use. Indian Aluminium Industry produces around 12,000tons ton of SPL per annum which needs to be effectively used.

Chemical Composition of SPL:
SPL contains both Carbonaceous and Refractory portions. Their compositions are furnished in Table -2.

Table-2 Chemical Composition of SPL.

Constituents	% by Wt.	
	Carbonaceous Portion	**Refractory Portion**
Carbon	50-52	-
CaO	0.2-0.4	1-2
Na_2O	18-20	12-20
SiO_2	0.2-0.6	15-18
Al_2O_3	12-13	40-50
Fe_2O_3	0.5-1.0	3-4
Cyanide	0.1-0.2	-
Fluoride	10-12	13-15

Application of SPL:
Various In-house and Collaborative R&D Projects have been successfully undertaken with reputed National R&D Institutions in this regard. They are:

(i) Characterization of SPL and Development of Process Flow Sheet for Extraction of Valuables like Carbon and Fluoride Salts of Sodium and Aluminium in Collaboration with Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC), Nagpur.

(ii) Development of SPL Cement in Collaboration with NCB, Ballavgarh, Haryana. The process has been patented.

(iii) Investigation on Utilization Potential of SPL as Co-fuel in the Boilers of Coal based Thermal Power Plants in Collaboration Central Fuel Research Institute, Dhanbad. The process has been patented.

(iv) Management of SPL – A Hazardous Waste Material of Aluminium Smelter Plant: A Pilot Plant Study in Collaboration with Institute of Minerals and Materials Technology, Bhubaneswar [6-11].

(C) Utilization of Fly Ash:

In India , most of the Thermal Power Plants use bituminous coal as fuel, which contains high amount of ash (up to 40%), sulphur (0.2-0.6 %), and heavy metals in varying proportions, where as the coal produced in countries like the USA is rich in sulphur (2%)

and contains only 5-10% Ash. A typical modern coal fired station in India burns 0.7T/MW/hr of coal and will consequently generate ash @0.28 T/MW/hr. There are about 82 Thermal Power Plants in India which form the major source of Fly Ash in the Country. The current production of Ash is about 100 million tones per year. Most of the ash generated from the power plants is disposed off in the vicinity of the plant as a host material covering several hectors of valuable land. Evolving suitable and appropriate methodologies for safe disposal and bulk utilization of fly ash is the challenge before the thermal power generators / Fly Ash Producers. Characterization of Indian Fly Ash is furnished in Table-3.

Table -3 Characterization of Indian Fly Ash:

Constituents	% by Wt.		Constituents	% by Wt.
SiO_2	62.72		CaO	2.33
TiO_2	0.81		Na_2O	0.19
Al_2O_3	29.93		K_2O	0.25
Fe_2O_3	2.13		LOI	0.52
MgO	0.72			

Application of Fly Ash:

Indian Scenario:

(i) Fly ash is mostly used in Cements and Concretes.

(ii) It is also used as Building material in construction activities.

(iii) Utilization of Fly Ash as filling materials for mines and embankments.

(iv) Use of Fly Ash in Wasteland Development and Agriculture in collaboration with Advanced Materials & Processes Research Institute, Bhopal [12].

(v) Technology Demonstration Projects like: Agriculture related studies and application, Reclamation of Ash Pond for Human settlement, Construction of Roads and Embankments, Rising of Ash dykes with ash, Dry Fly ash collection & bagging system for use by entrepreneurs and Fly ash sewage sludge and other organic matter in soil re- mineralization have yielded good results.

(vi) Development of Synthetic Granite Tiles in collaboration with Ceramic Technological Research Institute, Bharat Heavy Electricals Limited (BHEL), Bangalore [13].

(vii) Development of Fly Ash based Wear Resistant Ceramic products in collaboration with National Metallurgical Laboratory, Jamshedpur [14].

(viii) Process Development and Production of Fly Ash Bricks [1-3].

(ix) Development of Fly Ash based Fiber Reinforced Polymer Composites for Building Components as wood substitute in collaboration with Advanced Materials and Processes Research Institutes, Bhopal [4].

Results & Discussion:

Application of Red Mud

(i) Development of Red Mud Cement (Ferrite Cement) in Collaboration with NCB, Ballavgarh, Haryana. [Patented Process]

A collaborative R&D Project has been successfully completed with NCB, Ballavgarh, Haryana using Red Mud of NALCO origin and a suitable process has been developed for the production of Ordinary Portland Cement (OPC) from a raw mix containing limestone, red mud, shale and fine coal. Such a raw mix is fired in a kiln to a temperature of 1400-1500^{0}C to obtain clinker. Clinker is cooled and gypsum is added thereto to obtain the product OPC.

Preparation & Evaluation of Ordinary Portland Cement

Ordinary Portland Cement was prepared by grinding the bulk clinker so prepared above with 5.0% Gypsum to a fineness of ~300 m^2 /kg and tested for various properties and the results are presented in Table-4.

Table-4 Properties of Ordinary Portland Cement

Sl. No.	Property	Results	Requirement of IS:12269-1987 (53 Grade OPC)
1.	Fineness (M^2 /kg)	305	Not less than 225
2.	Setting Times (Min.)		
	Initial	158	Not Less than 30
	Final	254	Not more than 600
3.	Compressive Strength (N/mm^2)		
	3 Days	29.0	Not less than 27
	7 Days	42.5	Not less than 37
	28 Days	65.8	Not less than 53
4	Soundness		
	Le-chatelier (mm)	1	Not more than 10
	Autoclave (%)	0.027	Not more than 0.8

(ii) Development of Red Mud Bricks in Collaboration with Institute of Minerals and Materials Technology, Bhubaneswar.

Properties of Cold Setting Building Bricks manufactured from different waste materials such as Fly Ash, Iron Ore Tailings, and Red Mud by Mineral Polymerization process have been compared as per Bureau of Indian Standards (BIS) Specification. Comparison of properties of bricks produced from different waste materials are furnished in Table-5.

Table-5 Comparison of Brick Properties

Brick Properties	Type of Waste Material	Building Brick Specification (Class 7.5)

	Fly Ash	Iron ore tailings	Red Mud	Fired clay-sand BIS1077: 1992	Fly ash - Lime BIS12894: 2002
Mix wt. %	80 - 95	50-70	50-70		50 %
Brick size (mm)	230x110x75	230x110x75	230x110x75	230x110x75	230x110x75
Dry wt. (kg)	2.700 - 3.000	3.100 - 3.500	2.800 – 3.200	Not specified	Not specified
Dry Bulk density (gm/cc)	1.35 - 1.45	1.75 - 1.90	1.40 - 1.60	Not specified	Not specified
Water absorption. (%)	10 - 16	8 - 12	10- 14	20	20
Dry Crushing strength (kg/cm²)	80 - 150	80 - 160	80 - 155	75	75
Wet Crushing strength	75 - 140	75 - 150	75 - 145	Minimum 80% of dry crushing	Minimum 80% of dry crushing
Prodn. cost / brick (Rs.)	2.20 – 2.60	2.20 – 2.50	2.20 – 2.50	- -	--

(iii) Development of Red Mud Fiber Reinforced Polymer Composites for Building Components as Wood Substitute in Collaboration with Advanced Materials and Processes Research Institute, Bhopal. [Patented Process].

A collaborative R&D Project has been successfully completed in collaboration with Advanced Material & Processes Research Institute, Bhopal based on Red Mud of NALCO origin and large number of Red Mud based synthetic wood products like door and window shutters . partition boards, sofa sets with central table, air condition case etc. have been manufactured. The study reveals that Jute Fiber Reinforced Red Mud Polymer Composites (JRMPC) is stronger than wood, fire retardant and rot, rodent, termite and corrosion resistant. The door shutters fabricated using this material conforms to the IS4020:1994 standards and has also been approved by Central Public Works Department, Govt. of India, New Delhi. The process has been patented in India.

(iv) Recovery of Iron from Red Mud through Romelt Process in Collaboration with Moscow Institute of Steel and Alloys (MISA), Moscow, Russia.

A Joint Research Project and preparation of Techno-Economic Feasibility Report (TEFR) has been completed in collaboration with Moscow Institute of Steel and Alloys (MISA). Moscow. Russia and Romelt SAIL India Limited (RSIL). New Delhi for

extraction of Iron from NALCO Red Mud using Romelt Technology developed by MISA, Moscow, Russia. Though laboratory scale results were promising, techno-economic feasibility of the process could not be established.

(v) Study on Effect of Red Mud- Lime Flux Treatment on the Microstructure and Mechanical Properties of Steel in Collaboration with Indian Institute of Technology, Kharagpur West Bengal.[Patented Process]

Effect of using Red Mud and CaO mixture as a flux during steel making has been investigated. It has been concluded that Red Mud and CaO treatment of liquid steel results in refinement of ferrite grain size, increase in pearlite content and improvement of mechanical properties in forged normalized steel.

Application of SPL:

(i) Characterization of SPL and Development of Process Flow Sheet for Extraction of Valuables like Carbon and Fluoride Salts of Sodium and Aluminium in Collaboration with Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC), Nagpur.

A collaborative R&D Project has been successfully completed with JNARDDC, Nagpur and SPL has been characterized. In addition, a process flow sheet has also been developed for extraction of valuables present in SPL like Carbon and Fluoride Salts of Sodium and Aluminium.

(ii) Development of SPL Cement in Collaboration with National Council for Cement and Building Materials, Ballavgarh, Haryana. [Patented Process]

A collaborative R&D Project has been successfully completed in collaboration with NCB, Ballavgarh, Haryana and a suitable process has been developed for manufacture of Ordinary Portland Cement (OPC) from NALCO SPL. The process has also been patented in India. A raw mix of limestone, iron ore, bauxite, SPL and fine coal were fired in a kiln to a temperature of 1400 to 1450°C to obtain clinker, the clinker was cooled and on adding gypsum thereto, OPC was formed.

Preparation and Evaluation of OPC:

The results of the investigation are presented in Table -6.

Table-6 Properties of OPC

Sl. No.	Property	Control OPC- C Without SPL	OPC- 2 With SPL	Requirement of IS:12269-1987 (53 Grade OPC)
1.	Fineness (M^2/kg)	288.0	299.1	Not less than 225

2.	Setting Times (Min.) Initial Final	98 162	83 160	Not less than 30 Not more than 600
3.	Compressive Strength (N/mm^2) 3 Days 7 Days 28 Days	31.0 47.5 56.1	33.4 48.3 58.0	Not less than 27 Not less than 37 Not less than 53
4.	Soundness Le-chatelier Exp. (mm) Autoclave Exp. (%)	1.2 0.032	1.0 0.043	Not more than 10 Not more than 0.8

(iii) Investigation on Utilization Potential of SPL as Co-fuel in the Boilers of Coal based Thermal Power Plants in Collaboration Central Fuel Research Institute, Dhanbad, Jharkhand.[Patented Process]

A collaborative R&D Project has been successfully completed with Central Fuel Research Institute (CFRI), Dhanbad on Utilization Potential on SPL as a Co-fuel for use in the boilers of coal based Thermal Power Plants. The process has also been patented in India. The study had been undertaken with the primary objective of assessing the potential of using SPL as a blend component with high volatile non coking coal for power generation. The combustion studies of coal with different proportions of SPL show that addition of SPL up to 1% can be considered without any loss of the burnout efficiency of the parent coal.

(iv) Management of SPL – A Hazardous Waste Material of Aluminium Smelter Plant : A Pilot Plant Study in Collaboration with Institute of Minerals and Materials Technology (IMMT), Bhubaneswar

A Collaborative R&D Project in Pilot Plant Scale has been successfully completed with IMMT, Bhubaneswar utilizing SPL of NALCO origin and a suitable process has been developed for recovery of Carbon Value adding economic credit to the process. Fluoride and cyanide content was brought down to a level whereby the recovered carbon is safe for handling, storage and use.

Application of Fly Ash:

(i) Use of Fly Ash in Wasteland Development and Agriculture in Collaboration with Institute of Advanced Materials and Processes, Bhopal.

Studies on Long term effect of Coal ash/ Pond ash on Agriculture system have been successfully carried out in collaboration with Advanced Materials and Processes Research Institute, Bhopal. Characterization of Pond ash and Soil for optimization of the dose for agriculture has been carried out for physical and chemical properties as well as trace elements and radio nuclides etc. 20-25% increased crop yield has been clearly noticed due to favorable soil modification.

(ii) Development of Synthetic Granite Tiles in Collaboration with Ceramic Technological Institute (CTI) ,Bharat Heavy Electricals Limited (BHEL), Bangalore.

A novel process for production Synthetic Granite Tiles from Fly Ash has been successfully developed in collaboration with CTI, BHEL, Bangalore. Since the Fly ash was not sintering by itself, even at a temperature of 1300^0C, a suitable "Bond" material was added so as to densify the material. This "Bond" is basically an alumino-silicate with higher percentage of Sodium & Potassium which melts and form glass. Typical green density of the tiles produced was 1.3 gm/cc.

(iii) Development of Fly Ash based Wear Resistant Ceramic products in Collaboration with National Metallurgical Laboratory, Jamshedpur.

Fly Ash in the range of 15-38% has been used as a substitute of Alumina to develop wear resistant ceramic products for material handling equipment by sintering at 1600^0C for 2 hours in air. The microstructure and wear resistant properties of the sintered samples were evaluated with respect to Fly ash content. By comparing with high alumina ceramic liners (85% Al_2O_3), it was found that addition of 15% Fly ash has improved the wear resistant properties while 25% Fly ash based products give the properties at par with conventional high alumina ceramic liners.

(iv) Development of Fly Ash based Fiber Reinforced Polymer Composites for Building Components as Wood Substitute.

A suitable process technology has also been developed for manufacture of Fly ash based Fiber Reinforced Polymer Composites for Building Components as Wood Substitute in collaboration with Advanced Materials and Processes Research Institute, Bhopal. The process is similar to that of Development of Red Mud based Fiber Reinforced Polymer Composites for Building Components as Wood Substitute.

Conclusions:

From the above R&D/ Field Trials/ Pilot Scale studies it can be concluded that waste materials generated by Indian Aluminium Industry viz. Red Mud, SPL and Fly Ash from the Coal based Thermal Power Plants can be suitably utilized techno-commercially in bulk scales for sustainable development. The processes described are eco-friendly & have novelties and uniqueness in character and if implemented, it can convert waste in to wealth.

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PRODUCTION OF ORDINARY PORTLAND CEMENT (OPC) FROM NALCO RED MUD

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Abstract

A process for production of Ordinary Portland Cement (OPC) from NALCO Red Mud has been successfully developed from a raw mix containing limestone, red mud, shale and fine coal. The raw materials are ground to the required fineness and then blended to prepare the raw mix. The raw mix is fed in to a kiln and fired to a temperature of 1400-1450 degree centigrade to obtain clinker. Clinker was cooled and gypsum was added in to it to obtain OPC. 3-3.5% of NALCO red mud was used for production of OPC.OPC prepared from this clinker conformed to the requirements of three Indian Standard Specifications for 33, 43 & 53 grade of OPC. The process is efficient, cost-economic and effectively addresses the environmental problems associated with the waste red mud generated during the refining of bauxite for alumina manufacture.

Introduction

National Aluminium Company Limited (NALCO), a Navaratna Company and a Govt. of India Enterprise under Ministry of Mines has set up Asia's largest integrated alumina and aluminium complex in the state of Orissa, utilizing state of the art technology from Aluminium Pechiney, France and is producing 4,8,00,000 tpa of bauxite, 1,5,75,000 tpa of alumina, 3, 45,000 tpa of aluminium metal and 960MW of captive power. During the refining of bauxite for production of alumina employing the Bayer process at NALCO's alumina refinery, at Damanjodi in the district of Koraput, Orissa, on a dry basis about 2 million tones /annum of red mud is generated as a by-product. The red mud contains more than 55% water and is disposed off in the form of slurry in to the nearby red mud pond. The accumulated quantity of red mud in the ponds is estimated to be around 18.5 million tones. The water overflowing the pond after the mud is settled, is recycled to the alumina plant for partial recovery of soda. Therefore, the soda content in red mud is minimized. It was thought prudent to explore the possibilities for utilization of this uncausticised red mud dried in air/sunlight for production of value added items. Development of Ordinary Portland Cement (OPC) was one of the most positive efforts undertaken in this direction [1]. NALCO in collaboration with National Council for Cement & Building Materials (NCB), Ballavgarh, and Haryana, India has developed this process.

Table 1. Chemical Composition of NALCO Red Mud.

Constituents	% By Weight
Al_2O_3	16.13
Fe_2O_3	53.92
TiO_2	04.82
SiO_2	06.29
Na_2O	03.45
CaO	01.88
P_2O_5	00.11
V_2O_5	00.11
LOI	11.78

Sample Collection & Sampling

Five shift samples of red mud, bauxite and fly ash were collected. Red mud samples were designated as RMD-1 to RMD-5.

Red Mud:

Five shift samples of red mud weighing about 25kgs each were dried in electric oven at temperature of 105±5°C. The dried lumps in the samples were crushed. The samples were reduced to ~3kg by coning and quartering procedure and ground to pass through 100 mesh sieve. The laboratory samples were prepared by drawing ~200gms from each shift samples by coning and quartering procedure and were subjected to chemical and mineralogical characterization. The results of chemical and mineralogical characteristics of these laboratory samples are discussed in the following section.

Limestone and Other Raw Materials:

Limestone and other raw materials viz. shale, coal and gypsum samples were ground to pass through 100 mesh sieve. The laboratory samples of these raw materials were prepared by drawing ~200gms from each of the ground by coning and quartering procedure. The results of chemical and mineralogical characterization of these samples are discussed in the following section.

Characterization and Evaluation of Samples

Red Mud Samples:

(a) Quality and quality variation. Five ground samples of red mud (RMD-1 to RMD-5) were subjected to chemical analysis for their major constituents' viz. LOI, SiO_2, Fe_2O_3, Al_2O_3 and alkalies for assessing their quality and the variation therein. The results are presented in Table-2 indicated the variation in the composition of red mud shift samples with respect to major oxides to be low. In view of this, all the five shift samples of red mud were mixed together to make a composite sample. The composite sample was designated as RMD-C. Further investigations were carried out on the composite sample of red mud, RMD-C only.

Table 2 Quality and Quality Variation in Shift Samples of Red Mud

Sl No	Constituent Determined (%)	Shift I RMD-1	Shift II RMD-2	Shift III RMD-3	Shift IV RMD-4	Shift V RMD-5
1	LOI	11.32	11.86	11.03	11.13	11.64
2	SiO_2	6.32	6.35	6.48	6.07	5.90
3	Fe_2O_3	50.10	49.70	50.15	50.52	49.57
4	Al_2O_3	20.51	20.70	21.07	20.14	20.55
5	Na_2O	4.07	4.11	3.40	3.50	3.78
6	K_2O	0.07	0.08	0.06	0.06	0.06

Red Mud Composite Sample (RMD-C):

(a) Chemical Characterization. The composite red mud sample, RMD-C was subjected to chemical analysis and the results are presented in Table-3.

Table 3. Chemical Analysis of Composite Red Mud Sample (RMD-C)

Sl No	Constituents Determined (%)	Results
1	LOI	11.45
2	SiO_2	6.32
3	Fe_2O_3	49.62
4	Al_2O_3	20.74
5	CaO	2.45
6	MgO	0.15
7	SO_3	0.08
8	Na_2O	3.66
9	K_2O	0.07
10	P_2O_5	0.33
11	TiO_2	4.76
12	Mn_2O_3	0.11

(b) Mineralogical Characterization. X-ray diffraction analysis of the composite red mud sample, RMD-C indicated the presence of gibbsite and hematite as major minerals and goethite as minor mineral.

Other Raw Materials:

Limestone:

(a) Chemical Characterization: The limestone sample was subjected to chemical analysis and the results are presented in Table-4. The sample can be classified as cement grade limestone.

Table 4.Chemical Analysis of Raw Materials

Sl.No.	Constituents Determined (%)	Limestone	Shale	Gypsum	Coal Ash
1	LOI	37.25	2.72	17.10CW	0.87
2	SiO_2	10.78	85.93	11.44(+IR)	58.64
3	Fe_2O_3	0.81	1.14	0.26	6.25
4	Al_2O_3	1.95	7.22	NIL	25.85
5	CaO	44.90	0.58	28.85	3.19
6	MgO	3.06	0.21	0.66	0.67
7	SO_3	0.00	0.13	39.90	1.72
8	Na_2O	0.13	0.18	0.24	0.08
9	K_2O	0.73	1.76	0.04	0.83
10	TiO_2	-	0.27	-	1.56
11	Cl^-	0.008	0.01	-	0.017

(b) Mineralogical Characterization: X-ray diffraction analysis of the limestone sample indicated the presence of calcite as a major mineral and α-quartz, dolomite and muscovite as minor minerals.

Shale:

(a) Chemical Characterization: The shale sample was subjected to chemical analysis and the results are presented in Table-4.

(b) Mineralogical Characterization. X-ray diffraction analysis of the shale sample indicated the presence of α-quartz as major mineral and muscovite, yavapaiite and anorthite as minor minerals.

Gypsum:

(a) Chemical Characterization: The gypsum sample was subjected to chemical analysis and the results are presented in Table-4. The sample is considered suitable as a set retarder in the manufacture of cement.

(b) Mineralogical Characterization: X-ray diffraction of the gypsum sample indicated the presence of gypsum as a major mineral and α-quartz and albite as minor minerals.

Coal:

(a) Chemical Characterization: The results of proximate analysis of the coal sample are presented in Table-5. The ash prepared from the above coal was subjected to chemical analysis and the results are presented in Table-4

Table 5. Proximate Analysis of Coal Sample.

Sl.No.	Characteristics	Results
1	Ash Content (%)	35.34
2	Moisture Content (%)	1.82
3	Volatile Matter (%)	30.04
4	Fixed Carbon (%)	32.80
5	Calorific Value(kcal/kg)	5140

The above results of chemico-mineralogical characteristics of red mud, limestone and other raw materials indicate that their matrix is compatible with the cement matrix and can be used in the manufacture of cement.

Technical Suitability of NALCO Red Mud for the Manufacture of Cement

Chemical and mineralogical analysis of the NALCO red mud sample indicated that its composition is quite compatible with the cement matrix. Therefore, the NALCO red mud sample was considered prima-facie suitable for its gainful utilization in the manufacture of Ordinary Portland Cement (OPC)clinker in combination of other raw materials viz. limestone, shale and fine coal [2 -5]. The process of making OPC is discussed below.

Raw Mix Design & Its Optimization:

The Approach: While designing the raw mixes, attempts were made to maximize the use of red mud, RMD-C as raw mix component in the raw mix design for the manufacture of OPC. Keeping this in mind a large number of different raw mixes were designed to achieve good quality clinker. The proportions of raw material in the raw mixes designed (RM-1 to RM-5) are shown in Table-6. The design parameters optimized in the designed raw mixes are shown in Table-7-11.

Table-6. Various Raw Mix Designs Prepared

Raw Mix No.	Red Mud (%)	Shale (%)	Limestone (%)	Coal Ash Absorption(%)
RM-1	3.00	2.30	94.70	4.75
RM-2	3.50	2.14	94.36	4.75
RM-3	4.00	1.98	94.02	4.75
RM-4	4.30	1.89	93.81	4.75
RM-5	5.00	1.66	93.34	4.75

Table-7. Design Parameters of Raw Mix RM-1

Raw Materials	Red Mud		Limestone		Shale	Coal Ash Absorption
Proportion (%)	3.00		94.70		2.30	4.75
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO Na_2O K_2O
Raw Mix	35.68	12.37	2.28	2.63	42.61	MgO: 2.91 Na_2O: 0.24 K_2O: 0.73
Clinker		21.11	3.68	5.13	63.25	MgO: 4.34 Na_2O: 0.35 K_2O: 1.13
Modulii Values	LSF		SM		AM	Liquid Content(%)
RawMix	1.08		2.52		1.15	29.25
Clinker	0.93		2.40		1.40	
Potential Phase	C_3S		C_2S		C_3A	C_4AF
Composition(%)	57.32		17.32		7.37	11.19

Table-8. Design Parameters of Raw Mix RM-2

Raw Materials	Red Mud		Limestone		Shale	Coal Ash Absorption
Proportion (%)	3.50		94.36		2.14	4.75
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO Na_2O K_2O
Raw Mix	35.61	12.23	2.53	2.72	42.47	MgO: 2.90 Na_2O: 0.25 K_2O: 0.73
Clinker		20.08	4.03	5.25	62.97	MgO: 4.32 Na_2O: 0.38 K_2O: 0.76
Modulii Values	LSF		SM		AM	Liquid Content(%)
RawMix	1.08		2.43		1.08	30.03
Clinker	0.93		2.25		1.30	
Potential Phase	C_3S		C_2S		C_3A	C_4AF
Composition(%)	56.64		17.17		7.08	12.27

Table-9. Design Parameters of Raw Mix RM-3

Raw Materials	Red Mud		Limestone		Shale	Coal Ash Absorption
Proportion (%)	4.00		94.02		1.98	4.75
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO Na_2O K_2O
Raw Mix	35.53	12.09	2.77	2.80	42.32	MgO: 2.89 Na_2O: 0.27 K_2O: 0.49
Clinker		20.65	4.39	5.37	62.69	MgO: 4.30 Na_2O: 0.40 K_2O: 0.76
Modulii Values	LSF		SM		AM	Liquid Content(%)
RawMix	1.08		2.17		1.08	31.17
Clinker	0.93		2.12		1.22	
Potential Phase	C_3S		C_2S		C_3A	C_4AF
Composition(%)	55.94		17.04		6.80	13.35

Table-10. Design Parameters of Raw Mix RM-4

Raw Materials	Red Mud		Limestone		Shale	Coal Ash Absorption
Proportion (%)	4.30		93.81		1.89	4.75
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO Na_2O K_2O
Raw Mix	35.49	12.01	2.92	2.85	42.24	MgO: 2.88 Na_2O: 0.28 K_2O: 0.72
Clinker		20.52	4.62	5.44	62.51	MgO: 4.29 Na_2O: 0.42 K_2O: 0.75
Modulii Values	LSF		SM		AM	Liquid Content(%)
RawMix	1.08		2.11		0.98	31.86
Clinker	0.93		2.04		1.18	
Potential Phase	C_3S		C_2S		C_3A	C_4AF
Composition(%)	55.44		17.03		6.63	14.00

Table-11. Design Parameters of Raw Mix RM-5

Raw Materials	Red Mud		Limestone		Shale	Coal Ash Absorption
Proportion (%)	5.00		93.34		1.66	4.75
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO Na_2O K_2O
Raw Mix	35.39	11.80	3.26	2.97	42.04	MgO: 2.87 Na_2O: 0.31 K_2O: 0.48
Clinker		20.19	5.10	5.61	62.13	MgO: 4.26 Na_2O: 0.46 K_2O : 0.75
Moduli Values	LSF		SM		AM	Liquid Content(%)
RawMix	1.09		1.90		0.91	33.45
Clinker	0.93		1.89		1.10	
Potential Phase	C_3S		C_2S		C_3A	C_4AF
Composition(%)	54.53		16.78		6.24	15.51

Raw Mix Preparation.

Raw mixes, RM-1 to RM-5 were prepared by taking weighed quantities of raw materials as per the designs, blending them thoroughly and grinding the mixes to fineness of 10% residue on 90μ(170 mesh) sieve. Nodules of about 1 cm in diameter were prepared by mixing about 12% water and were dried in an electric oven at 105±5° C for about 2 hrs before subjecting them to burnability studies.

Burnabilities Studies:

Burnability studies were carried out on all the raw mixes. The dry nodules were introduced in to a laboratory furnace at ambient temperature, which was gradually raised to 1450°C. The raw mixes were fired at 1300, 1350, 1400 and 1450°C with a retention time of 20 minutes. The clinkers, CL-1 to CL-5, prepared from the raw mixes, RM-1 to RM-5 respectively were room cooled and their free lime content determined. The results of free lime determination are presented in Table-12 which indicate that all the raw mixes have good burning characteristics and are capable of yielding quality clinkers even at 1450°C with a retention time of 20 minutes. The free lime content in all the clinker samples was found to be < 0.50% at 1450°C.

Optimization of Raw Mix Design:

While designing the raw mixes, every effort was made to keep the level of utilization of red mud to the maximum extent possible. All the raw mixes prepared viz. RM-1 to RM-5 yielded good quality clinkers when test fired during burnability studies at 1450 °C with retention time of 20 minutes. But, keeping in view the maximum utilization of red mud, design parameters and process implications there from, raw mix RM-2 was taken as the optimized raw mix design. Although the red mud could be utilized up to 5% in the raw mixes designed, the raw mix RM-2 was selected to avoid process problems attributed to the presence of a high proportion of fluxing agents (Al_2O_3 and Fe_2O_3) in such raw mixes. From Table-7 to 11, it is found that on increasing the red mud content from 3.0% to 5.0%, the liquid content was found to be increased continuously. The presence of increased liquid content known to cause process implications in the cement manufacture and especially beyond 30% liquid content is detrimental to the life of refractory lining of the kiln. Generally, the liquid content has been maintained in the range of 27 to 30% in cement manufacture. 3.5% has been selected as the optimal red mud content keeping in mind the maximum utilization of red mud in cement manufacture. Its liquid content is 30.03% and is on border line but is still in an acceptable range. On going from red mud content of 3.5 to 5%, the liquid content increases from 30.03% to 33.45% and the resultant clinkers were found to be sticky to the refractory linings and will reduce the life of the refractory linings and have many process implications. Also, the presence of high liquid content results in the formation of boulders instead of normal sized clinkers which further makes problems in the process. The role of fluxing agents like Fe_2O_3, Al_2O_3 etc is very critical in the formation of clinker. The general range for Al_2O_3 content is 4 to 7% and for Fe_2O_3 is 2 to 4% in the clinker. The details of the optimized raw mix RM-2 is given in Table-8. The raw mix RM-2 is capable of yielding good quality clinker at 1450°C with a retention time of 20 minutes.

Table 12.Burnability Studies of Cement Raw Mixes with Red Mud as a Component (Retention Time 20 Minutes)

Sl. No.	Raw Mix	Temperature(°C)	Free Lime %
1	RM-1	1300	1.66
		1350	0.82
		1400	0.32
		1450	0.06
2	RM-2	1300	1.73
		1350	0.88
		1400	0.34
		1450	0.06
3	RM-3	1300	2.44
		1350	1.57
		1400	0.55
		1450	0.13
4	RM-4	1300	2.35
		1350	1.18
		1400	0.44
		1450	0.09
5	RM-5	1300	1.73
		1350	0.61
		1400	0.31
		1450	0.15

Preparation and Evaluation of Bulk Clinker

10 kg sample of optimized raw mix RM-2, selected for detailed investigations was prepared by taking weighed quantities of raw materials viz. red mud, limestone, shale and coal ash as per its raw mix design, blended them in a ball mill and ground to a fineness of 10% residue on 90μ(170 mesh) sieve. The nodules were prepared in a pan nodulizer and dried in an electric oven at 105±5 °C for 2 hrs before introducing in an electric furnace at ambient temperature and eventually firing it at 1450 °C for 20 minutes. The resultant clinker CL-2 from raw mix RM-2 was

studied for chemical, mineralogical and grinding characteristics and the OPC prepared there from was evaluated for performance as per relevant Indian Standard Specifications. Three batches of such bulk clinkers, 10kgs each, were prepared by adopting the same procedure to evaluate the reproducibility of the results.

Chemical Analysis:

The chemical analysis of the bulk clinker, CL-2, carried out as per Indian Standard Specification, IS: 4032-1985 and is presented in Table-13. These results indicated that the quality of the clinker was good and capable of yielding good quality cement.

Table 13. Chemical Analysis of Bulk Clinker

Sl. No.	Constituents Determined	Results Obtained (%)
1	LOI	0.35
2	SiO_2	20.60
3	Fe_2O_3	4.02
4	Al_2O_3	5.30
5	CaO	63.27
6	MgO	4.22
7	SO_3	0.27
8	Na_2O	0.38
9	K_2O	0.78
10	Cl^-	0.003
11	Insoluble Residue	0.38
12	Free Lime	0.25

Mineralogical Analysis:

The clinker sample CL-2 from raw mix RM-2 was evaluated for its mineralogical composition by optical microscopy and the results along with the granulometry of the clinker phases are presented in Table-14. Clinker phases are moderately developed and are homogenously distributed. Majority of alite grains are subhedral in shape. Few pseudo hexagonal alite grains are also developed in the clinker. Transformation of belite into alite has also been observed. Some belite clusters were also presented in the sample. Few crystals of free lime were also present. It indicated that the quality of the bulk clinker sample so prepared was good.

Table 14. Mineral Phase Analysis of Bulk Clinker Sample by Optical Microscopy

Sl. No.	Clinker Sample	Phases	Quantity (%)	Granulometry (μm)		
				Min.	Max.	Avg. Size
1	CL-2	C_3S	48	3	18	12
		C_2S	33	3	17	10
		C_3A } C_4AF	18	-	-	-
		CaO_f	1	1	9	4

The X-ray diffractogram of the bulk clinker sample CL-2 indicated the presence of homogenously distributed and well developed phases.

Grindability Studies:

In order to determine the energy required for grinding clinker, laboratory grindability test was conducted using standard bond ball mill. The Bond Index for clinker, CL-2, has been found to be 10.9KWH/T which lies in between the range of Bond Index 9-13KWH/T. As this value of Bond Index lies on the middle of the range, the clinker appears to be hard enough in nature.

Reproducibility of the Clinker

In order to ascertain the reproducibility of the product i.e. clinker, two more batches of the clinker were prepared in the laboratory from the optimized raw mix, keeping the process parameters same as maintained during preparation of bulk clinker sample, CL-2.

Preparation and Evaluation of Two Additional Batches of the Clinker:

Two additional batches of the clinkers CL-2-A and CL-2-B were prepared by taking 10 kgs of raw mix RM-2 adopting the same procedure as described under Preparation and Evaluation of Bulk Clinker. The resultant clinkers designated as CL-2-A and CL-2-B were studies for chemical and mineralogical characteristics. The results are discussed below.

Chemical Analysis:

The chemical analysis of the two additional batches of clinkers, CL-2-A and CL-2-B, were carried out as per Indian Standard Specification, IS: 4032-1985 and the results are presented in Table-15. Results indicated that the chemical composition of both the clinkers, CL-2-A and CL-2-B, are comparable to the composition of the first batch of the clinker, CL-2.

Table 15. Compositional Variation in Three Batches of Clinkers

Sl. No.	Constituents Determined	Results Obtained (%)		
		CL-2	CL-2-A	CL-2-B
1	LOI	0.35	0.45	0.40
2	SiO_2	20.60	20.48	20.43
3	Fe_2O_3	4.02	4.12	4.18
4	Al_2O_3	5.30	5.29	5.26
5	CaO	63.27	63.24	63.35
6	MgO	4.22	4.23	4.26
7	SO_3	0.27	0.34	0.31
8	Na_2O	0.38	0.37	0.31
9	K_2O	0.78	0.69	0.77
10	Cl^-	0.003	0.004	0.006
11	Insoluble Residue	0.38	0.34	0.36
12	Free Lime	0.25	0.22	0.24

Mineralogical Analysis:

(a) Optical Microscopic Analysis: Samples from the two additional batches of clinkers, CL-2-A and CL-2-B, prepared in the laboratory ascertaining the reproducibility were evaluated for their mineralogical composition by optical microscopy. The results along with the granulometry of clinker phases are presented in Table-16. The alite grains were subhedral in shape. Transformation of belite into alite was observed in both the samples. Most of the belite grains were sub-rounded in shape with corroded margins. Few crystals of free lime were also observed in these two samples. The results have revealed that the granulometry and mineralogical characteristics of the two clinkers of additional batches, CL-2-A and CL-2-B, are comparable to the first batch the clinker i.e. CL-2.

Table 16. Variation in Mineral Phase Analysis of Three Batches of Clinker Samples by Optical Microscopy

Sl No	Clinker Sample	Phases	Quantity	Granulometry(μm)		
				Min.	Max.	Avg. Size
1	CL-2	C_3S	48	3	18	12
		C_2S	33	3	17	10
		C_3A + C_4AF	18	-	-	-
		CaO_f	1	1	9	4
2	CL-2-A	C_3S	45	3	19	11
		C_2S	34	4	17	11
		C_3A + C_4AF	17		-	-
		CaO_f	1	1	9	4
3	CL-2-B	C_3S	46	3	18	11
		C_2S	34	4	18	12
		C_3A + C_4AF	18	-	-	-
		CaO_f	1	1	9	4

(b) X- Ray Diffraction Analysis. Samples from the two additional batches of clinkers CL-2-A and CL-2-B, were also subjected to X- Ray diffraction analysis. It indicated the presence of homogenously distributed and well developed clinker phases in these two samples CL-2-A and CL-2-B, similar to the first batch of the sample, CL-2. The chemico-minerological evaluation of the results of the two additional batches of clinker samples, CL-2-A and CL-2-B, indicated their close resemblance to the clinker, CL-2, prepared in the first batch. Results have clearly established the reproducibility of the product i.e. clinker made from NALCO red mud.

Preparation and Evaluation of Ordinary Portland Cement (OPC)

Ordinary Portland Cement, OPC-2 was prepared by grinding the bulk clinker CL-2 so prepared with 5.0% gypsum to a fineness of ~300m²/kg and tested for setting time, compressive strength, Le-chatelier and autoclave expansion tests as per IS:4031-1988 and the results are presented in Table-17.

Setting Time.

The initial and final setting times of Ordinary Portland Cement prepared in laboratory from bulk clinker were determined as per IS: 4031-1988 and the results are presented in Table-17. The results indicated that the cement sample OPC-2 conformed to the requirements of the standard.

Compressive Strength:

The compressive strength of OPC-2 prepared above was determined as per IS: 4031-1988 and the results are presented in Table-17. The results indicated that the OPC-2 sample conformed to all requirements of all the three Indian Standard Specifications for 33, 43 and 53 grades of OPC viz. IS:269-1989, IS:8112-1989 and IS:12269-1987.

Soundness:

Autoclave and Le – chatelier expansion tests on OPC-2 prepared above were carried out as per the procedures laid down in IS: 4031-1988. The results indicated high volume stability of the cement sample and conformed to all the requirements of all the three Indian Standard Specifications for 33, 43 and 53 grades of Ordinary Portland Cements viz. IS:269-1989, IS:8112-1989 and IS:12269-1987 respectively.

Table 17.Performance of Ordinary Portland Cement (OPC)

Sl. No.	Property	Results	Requirement of IS:12269-1987 (53 Grade OPC)
1	Fineness(M^2/kg)	305	Not less than 225
2	Setting time (Min.)		
	Initial	128	Not less than 30
	Final	254	Not more than 600
3	Compressive Strength(N/mm²)		
	3 Days	29.0	Not less than 27
	7 Days	42.5	Not less than 37
	28 Days	60.8	Not less than 53
4	Soundness		
	Le-chatelier(mm)	1	Not more than 10
	Autoclave (%)	0.073	Not more than 0.8

The above results indicated that good quality clinker can be prepared by using 3.50% red mud, 94.36% lime stone and 2.14% shale. The Ordinary Portland Cement (OPC) prepared from this clinker conformed to all the requirements of three Indian Standard Specifications for 33, 43 and 53 grade of OPC. In addition, OPC made from 3.0% of NALCO red mud, 94.70% of lime stone and 2.30% of shale also confirmed to the above specifications. Complete performance evaluation of different OPC samples prepared from 3.0 and 3.5% of NALCO red mud was conducted.

Conclusions

Chemical and mineralogical analysis of NALCO red mud indicated that its composition is quite compatible with the cement matrix. The NALCO red mud therefore was considered prima-facie suitable as a raw mix component in the manufacture of OPC. While designing the raw mixes, every effort was made to keep the level of utilization of NALCO red mud to the maximum possible extent. Upto 5% red mud could be gainfully utilized in the raw mixes. However, to overcome process problems attributed to the presence of high proportion of fluxing agents (Al_2O_3 and Fe_2O_3) in other raw mixes, the raw mix RM-2 with 3.5% red mud was considered most suitable for the preparation of bulk clinker, CL-2. Physical performance of the OPC made from the bulk clinker, CL-2, utilizing 3.5% of NALCO red mud conformed to all the requirements of all the three Indian Standard Specifications for 33, 43 and 53 grades of OPC viz. IS:269-1989, IS:8112-1989 and IS:12269-1987 respectively. Reproducibility of the clinker made from NALCO red mud is also established.

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• *Source: Light Metals-2011, TMS International Conference held at San Diego, California, USA, February 27- March 3, 2011, pp 97-102.*

Keywords: Lateritic Ore, Chromite Over Burden(COB), Reduction Roasting, Magnetic Separation, Smelting Reduction, Fe-Ni

Waste to wealth: production of Fe-Ni from lateritic ore/chromite overburden of Sukinda deposit in Odisha, India

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In the Sukinda Valley of Odisha, India, the total quantity of nickel ore reserves comprising of both lateritic and chromite over burden(COB) have been estimated at around 231 million tonnes containing 0.3 to 0.9% Ni. While mining of one tonne of Chromite ore, around 6-7 tonnes of chromite over burden are removed. These overburden materials are disposed as waste materials, which causes lot of environmental hazards and ecological imbalance. India imports a large amount of nickel and ferro-nickel to meet its growing demands in various sectors. For import substitutions, efforts have been made to produced ferro-nickel from the lean deposits of nickel bearing lateritic ores/chromite over burden materials by reduction roasting followed by magnetic separation and then the nickel rich magnetic fraction is smelted to produce ferro-nickel. It has been possible to produce ferro-nickel of grade varying from 4-25% nickel.

Introduction

During mining of chromite ore, large quantities of overburden materials are being generated. The materials amount to approximately 10 million tonnes per year contain around 0.3-0.9% Ni, 0.02-0.06% Co, 20-50% Fe and 4-9% Cr_2O_3 depending upon the location and the depth of the mine. These materials presently do not find any application for the extraction of nickel due to lack of a suitable technology. The materials are also unsuitable for ferro-nickel making because of their very high iron to nickel ratio. The country is seriously looking for a suitable technology to utilize these resources as its entire domestic requirements of nickel is met though imports. In this connection, a systematic approach has been made at the Institute of Minerals and Materials Technology, Bhubaneswar to develop a process for ferro-nickel making from this indigenous resource.

In India, the only potential nickel-lateritic and cobalt-bearing deposits that contain extractable chromite exist in four parallel bands of Sukinda region in Odisha, India. It is estimated that this deposit contains around 130 million tonnes of chromite at a cut-off grade of 35% Cr_2O_3. While mining chromite ore, it becomes mandatory to remove the overburden materials from the hanging and footwalls on either side of the chromite band. The chromite mining activities in the Sukinda region have been in progress for the last four decades. The overburden materials generated until now are considered waste and cause of environmental hazards and ecological imbalances. The total quantity of nickel ore reserves comprising of both lateritic and over burden has been estimated at around 231 million tonnes containing 0.3 to 0.9% Ni. Moreover, M/S Jindal Steel Limited is setting up a 2.5 million tonnes of stainless steel plant in Kalinganagar, near Sukinda Valley; a large quantity of ferro-nickel will be required for the facility.

The Institute of Minerals and Materials Technology (IMMT), Bhubaneswar, has developed a state-of-the-art technology for complete utilization of nickel bearing lateritic ore/chromite overburden (COB) containing nickel by producing ferro-nickel, which can be used for manufacture of stainless steel. As a leading technology supplier in the field of minerals and materials technology in India, IMMT, Bhubaneswar is in a position to provide a novel and innovative

process for commercial production of Fe-Ni, which will undoubtedly fulfill the demand of nickel consumption in India by way of import substitution.

The complex nickel bearing lateritic ore COB can not be beneficiated strictly by physical means. The physical beneficiation process does not upgrade nickel or eliminate iron due to its complex and finely disseminated nature. To overcome this inherent problem, an innovative process has been developed by IMMT to convert the goethite into magnetite so that iron and nickel present therein can be easily separated from other gangue materials by employing techniques of reduction roasting followed by magnetic separation. This magnetic concentrate, which is rich in nickel, can be smelted to produce Fe-Ni very well in a commercial scale of the grade 4-25% Ni. This process is comparable to processes available elsewhere in the world for commercial Fe-Ni production. The process is a zero-waste process because the slag produced following the extraction of Fe-Ni can be efficiently utilized for cement manufacture.

Table-1 Composition of Lateritic ores used in Fe-Ni production in different countries

Plant and Source of Ore	Composition of Lateritic Ore			Grade of Fe-Ni
	Ni%	Fe%	Fe/Ni	Ni%
1. Pacific Metal Co. Ltd., Japan (Philippines)	1.37	28.30	20.66	24-30
2. Marro do Niquel S.A., Brazil	2.00	6.50	3.25	30.00
3. S.A. Le Nickel, Doniamboo, New Caledonia	2.80	13.00	4.64	22-28
4. Sumitomo Metal and Mining Co., Japan (New Calendinia Ore)	1.46	1.63	1.12	27
5. P.T. International Nickel, Indonesia	1.62	14.10	8.70	-
6. Kovadarei, Yugoslavia	1.57	10.60	6.75	25.00
7. Hana Nickel Smelting Co., Riddle, Oregon	1.65	12	7.27	47.00
8. Larco, Greece	1.70	38.00	22.35	22-33

World Technology Scenario

Nippon Yakin Kogyo Co. Ltd. developed a process for producing ferro-nickel by direct reduction of garnierite ore at the Oheyam works [8]. In this process, crude ferro-nickel is produced at low energy cost in a rotary kiln after pretreatment of the raw materials; the crude ferro-nickel is then used as the raw materials in the AOD stainless steelmaking process. A simplified mathematical model has been developed for the production of ferro-nickel from lateritic ores by the electric reduction furnace process (ERF Process) and the same has been applied satisfactorily at the plant of Larco at Larymna in Greece [9].

Nayak J.C [10] reported the results of an investigation for production of ferro-nickel from Sukinda laterites in rotary kiln-electric furnace process at Elkem's Laboratory in Norway. Nayak states that 20% nickel grade ferro-nickel was produced with high nickel recovery by selective reduction technique. The lateritic deposits in other parts of the world used in the extraction of nickel are given in Table-1.

Indian Technology Scenario

Nickel in India occurs in sulfide form along with copper mineralization in Singhbhum district of Bihar. It is being recovered as nickel sulphate crystals, as by-product of copper production. The other occurrence is nickeliferrous limonite in the overburden of chromite in Sukinda Valley, Jajpur district, Odisha [11]. This is an oxide ore and, hence, efforts are underway to develop a process for its utilization. Various organizations are trying to extract the metal values from chromite overburden materials. The process alternatives are: (i) production of Fe-Ni from imported and indigenous ore blend by Industrial Development Corporation (IDC), Odisha, (ii) extraction of pure nickel and cobalt from chromite overburden, ferro-nickel making and alloyed pig iron-making from chromite overburden by Institute of Minerals and Materials, Bhubaneswar [12-16], and (iii) efforts are also being made to extract nickel from chromite overburden through biotechnology means.

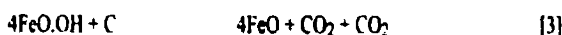
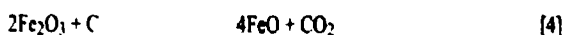
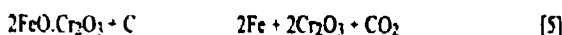
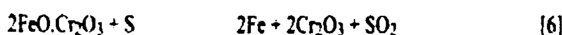
A typical composition of lateritic ore and chromite overburden in Sukinda region is given in Table-2. There is unfavorable Fe/Ni ratio in these materials, which require preferential treatment to remove large part of iron. The physical beneficiation process does not provide any significant nickel concentration or iron elimination due to the complex and finely disseminated nature of material. It is necessary to bring the ratio to an acceptable limit by some economic method prior to smelting. Reduction roasting is an effective unit operation in the treatment of iron oxide at elevated temperature, and it is carried out in the presence of both carbon, carbonaceous material and reducing gases like CO and H_2. Conversion of CO by CO_2

Table-2: Typical composition of Chromite Overburden and Lateritic ore of Sukinda

Constituents	Chromite Overburden %	Lateritic Ore (Kansa) %
Ni	0.50-0.90	1.20-1.30
Co	0.02-0.06	0.04-0.06
Fe	28.00-42.00	44.00-54.00
Cr_2O_3	4.00-9.00	1.50-3.00
MgO	0.50-2.50	0.10-1.50
Al_2O_3	5.00-12.00	1.50-3.00
SiO_2	9.00-38.00	9.00-11.00
LOI	9.00-14.00	10.00-13.00

is the main prerequisite for reduction. The reduction process is represented by the equations [1], [2], [3], etc


$$8FeO.OH + SiO_2 + 2C \quad Fe_2SiO_4 + 2Fe_3O_4 + 4H_2O + 2CO \quad [1]$$

$$4Fe_2O_3 + C + SiO_2 \quad Fe_2SiO_4 + 2Fe_3O_4 + CO_2 \quad [2]$$

$$4FeO.OH + C \quad 4FeO + CO_2 + CO_2 \quad [3]$$

$$2Fe_2O_3 + C \quad 4FeO + CO_2 \quad [4]$$

$$2FeO.Cr_2O_3 + C \quad 2Fe + 2Cr_2O_3 + CO_2 \quad [5]$$

$$2FeO.Cr_2O_3 + S \quad 2Fe + 2Cr_2O_3 + SO_2 \quad [6]$$

$$4FeO.OH + SiO_2 + 2C \quad Fe_2SiO_4 + 2Fe + 2H_2O + 2CO_2 \quad [7]$$

$$2Fe_2O_3 + SiO_2 + 2C \quad Fe_2SiO_4 + 2Fe + 2CO_2 \quad [8]$$

During preheating of the hydrated oxide mineral ore, goethite undergoes dehydration to form hematite. This reaction takes place in the range of 300-400°C.

The Innovative Process Know-how Developed at IMMT, Bhubaneswar

A state-of-the-art technology has been developed by Institute of Minerals and Materials Technology (IMMT), Bhubaneswar for complete utilization of nickel bearing lateritic ore/chromite over burden (COB) containing nickel for commercial production of ferro-nickel, which can be used for manufacture of stainless steel.

The nickel bearing lateritic ore/COB is in a complex state that cannot be beneficiated only by physical means. The physical beneficiation process does not provide any up-gradation of nickel or elimination of iron present therein due to its complex and finely disseminated nature. To overcome this inherent problem, an eco-friendly and zero waste innovative process know-how has been developed by IMMT to convert goethite phase present in ore bodies into magnetite phase so that iron and nickel present therein can be easily separated from other gangue materials viz. silica, alumina etc. by employing the reduction roasting technique followed by magnetic separation. The magnetic concentrate, which is rich in nickel, can be smelted to produce Fe-Ni in a commercial scale of the grade 4-25% Ni. This process is very well comparable with any of the processes available elsewhere in the world for commercial Fe-Ni production.

The main purpose of carrying out reduction roasting is selective conversion of the iron phase into magnetite, so that it can be removed magnetically. In mineral processing operation, the reduction is controlled to avoid formation of wustite, which is relatively nonmagnetic in nature. Since the nickel in Sukinda region is associated with iron phases, the adoption of reduction roasting technique is appropriate to separate nickel-rich iron concentrate from the associate gangue. The nickel concentrate thus, obtained by reduction roasting followed by magnetic separation route may be advantageous to enrich nickel content in reduced material. This reduced material then will be suitable for ferro-nickel making. A selective pre-reduction of the iron phase can be carried out in a rotary kiln with controlled parameters or a pan sintering unit designed and fabricated by IMMT, Bhubaneswar.

In this process, efforts have been made to produce ferro-nickel of the grade 4-25% nickel from the lateritic ore or chromite over burden by a pyrometallurgical process which includes sintering followed by magnetic separation and smelting of the magnetic fraction rich in nickel using induction furnace facility at IMMT, Bhubaneswar. The slag produced by this method can be used to manufacture cement, thereby making it an environmental friendly zero waste process.

Experimental

Chromite overburden fines (-150μ) containing 0.89% NiO and 45% Fe_2O_3 were mixed with -150μ coke breeze powder containing 65% fixed carbon in the required proportions. The mixture was granulated with 12% water in a disc pelletiser. The granules were then mixed with -2mm coke breeze and charged into the Down Draft Pan Sintering unit for reduction roasting (Figure 1).

A 10x10x310 mm laboratory-scale pan sintering was used in the experiments. About 50 g of charcoal pieces

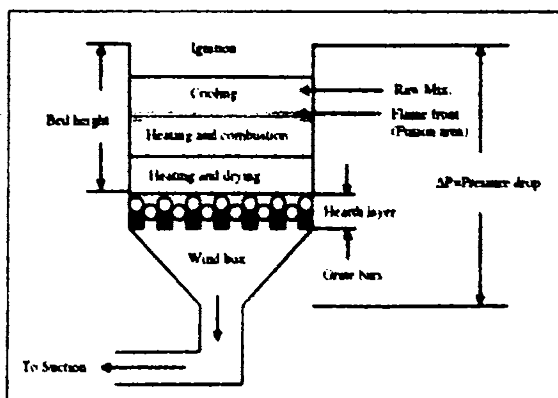


Figure 1 Schematic diagram of down draft sintering unit

were put on the top of the pan sintering unit for ignition. The bed height was maintained at 300-310 mm. Slow down-draft suction was initially applied for a minute to promote uniform ignition before the draft was increased to the required level.

The sintered product was ground to -75μ in a (wet) ball mill and then subjected to low intensity wet magnetic separation.

The wet magnetic separation was carried out on a low-intensity (2000 gauss) magnetic drum separator. The slurry was pumped into the drum at a rate of 300-400cc/minute. The drum speed was maintained at 45rpm. Magnetic and nonmagnetic fractions were collected separately, and then dried, weighed and analyzed for nickel and iron. The results are summarized in Table-3.

Table-3: Results of low intensity magnetic separation of [illegible] Ore. Feed ground to 80% passing 75µm, intensity of magnetic field - 2000 gauss

Details	Wt%	Fe%	Ni%	Fe/Ni	Ni Recovery	Fe Recovery
Roasted Feed	100	54.64	1.55	35.25	100	**100**
Mag. Fraction	73.30	58.89	1.94	30.40	91.74	**79.00**
Non-Mag. Fraction	26.70	43.00	0.47	91.50	8.26	**21.00**
1st cleaning of magnetic fraction						
Mag	67.10	59.33	2.04	29.10	88.30	73.10
Non-Mag	6.20	51.94	0.89	58.40	3.44	5.90
2nd cleaning of magnetic fraction after 1st cleaning						
Mag	64.00	59.76	2.09	28.60	86.30	70.00
Non-Mag	3.10	54.73	1.05	52.10	2.00	3.10



Figure 2: 35 kVA Induction furnace having three modules 5 kg, 10 kg and 20 kg capacity

The nickel-rich magnetic fraction was smelted in an induction furnace (alumina crucible) to produce ferro-nickel (Figure 2). The chemical analysis of metal and slag are given in Table-4.

Table 4: Smelting Analysis of Magnetic fraction of sinter product

Feed	Magnetic fraction of sinter product, **containing 2.[illegible]% Ni and 60% Fe**
Crucible material	Alumina
Temperature	1550°C

The data in Table-4 indicate that ferro-nickel containing 4-25% nickel can be obtained using 4-10% of reductant required

Exp. No	Charcoal %	Alloy			Slag		
		Wt%	%Ni	%Fe	Wt%	%Ni	%Fe
1	4.2	3.70	25.00	76.80	96.30	0.075	22.480
2	7.5	30.00	6.42	91.60	70.00	0.250	40.210
3	10.0	36.00	5.58	93.30	65.00	0.490	16.20
4	10.0	42.00	4.28	86.57	58.00	0.150	6.140

for reduction of iron oxide. Increase in the amount of reductant increases the yield and decreases the grade of ferro-nickel. This trend is quite similar to data reported elsewhere [10,12].

Results and Discussions

The chromite overburden/lateritic ore contains iron in the form of goethite and nickel is present in the lattice of goethite phase of iron. The main objective of the reduction process is to convert this goethite phase of iron into magnetite phase and separate it from gangue materials such as alumina, silica, etc. If the entire goethite phase of iron is converted into magnetite phase, then the Fe/Ni ratio will increase, thereby diluting the nickel grade during smelting. To overcome this problem, pan sintering technique was employed to selectively reduce iron oxide and nickel oxide such that the magnetic fraction becomes rich in nickel content. The fundamental study reveals that nickel oxide reduction occurs more rapidly than iron oxide reduction.

During pan sintering process, iron oxide reduces into magnetite, wustite and metallic iron forms. When this reduced product is subjected to magnetic separation, magnetite and metallic iron along with nickel are separated. A nickel-rich magnetic fraction is obtained and it becomes the feed material for the smelting reduction process. The results of magnetic separation studies are shown at Table-3. The underlying philosophy of the study reveals that the subsequent stages of magnetic separation of the magnetic fractions shows higher content of nickel.

The smelting reduction studies were carried out in an induction furnace using coke breeze fines as the reductant for production of ferro-nickel. The amount of reductant plays a vital role in smelting reduction process for selective reduction of iron for obtaining higher grade of ferro-nickel. Ferro-nickel containing various percentages of nickel therein can be produced by selectively reducing iron oxide by controlling the use of different percentage of reductant as shown in Table-4.

Conclusions

A state-of-the-art reduction roasting process followed by magnetic separation and smelting techniques has been shown to produce ferro-nickel containing 4-25% nickel from chromite overburden/lateritic ore containing nickel. The technology is environmentally friendly and zero-waste process accounting for complete conversion of waste material chromite overburden

IMMT, Bhubaneswar, operating under the aegis of Council of Scientific and Industrial Research (CSIR), Government of India, is in a position to provide this technology to the industrial houses/entrepreneurs for production of ferro-nickel in the pilot/ commercial scale any where in the world. A pre-feasibility report with plant capacity of 3000 tonnes per annum for production of ferro-nickel is available with IMMT Bhubaneswar for commercial exploitation of the process know-how. Patent application has been filed in India based on the above research findings.

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CHAPATER 8

Development of Coal Based Industries

Promotion of Coal Chemical Industry in Odisha

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Due to the fast depleting nature of oil and natural gas reserves in the absence of significant new discoveries, it is causing a dent in the Indian as well as Odisha economy keeping the self-sustainobility in picture. The over-dependence on import of fossil-fuel energy has further aggravated this problem to an unimaginable level. In this paper, the efforts have been made to discuss various ways and means to promote coal chemical industries in Odisha to tackle the above problems noticeably.

Introduction

At present, petroleum crude oil and coal constitute the basic source of hydrocarbons contributing much in the energy sector and as a basic raw material for chemical process industries.

The 20th century initiated a new transformation in the use of conventional materials in the field of consumer products and construction materials due to the discovery of polymers, plastics, and other petrochemical based products. Accordingly, the requirement of petroleum crude oil as charge stock for refineries has increased manifold not only to meet the needs of distillate fuel (motor gasoline. HSD, Kerosene), but also for light and heavy naphtha as raw material feedstock for different petrochemical industries.

From the current assessment and analysis, it is observed that the future of this raw material looks gloomy unless scientists come up with new discoveries (alternative sources of energy) or stern measures regarding conservation of resources are adopted. There have been efforts to develop alternative energy sources worldwide of which coal conversion technologies are the most sought after areas that are gaining momentum in the entire world. This picture is more prevalent in those developing nations which are going deficient in crude oil and having relatively better hydrocarbon resources in the form of non-coking coal.

Though India was little late to the party and joined the petrochemical field in the late sixties, she is trying hard to cope up with the developed nations in this aspect. Also, the meager reserves of petroleum or natural gas in India worsen the situation further. Even after the new finds of oil and natural gas in the offshore regions of Bombay High and dry natural gas of South Bassein that is devoted completely to serve fertiliser based projects and power plants, the anticipation to pursue petroleum based energy policy as long-term strategy still sees a backdoor. Against this circumstance and background, India is comfortably placed in case of coal reserves that is traditionally her primary energy source. India has significant reserves of coal, and the latest estimate of them indicate a level that is little over 12 billon tonnes in seam thickness of 0.5 m and up to a depth of 1200 m. This hefty amount of reserves is expected to last for 200 to 300 years or even more regardless of their extensive use as traditional energy source. Considering the energy equivalence, India's coal resource is more than hundred times when compared to petroleum oil.

Coal as Raw Material for Chemical Industry

Considering the completion of all railway infrastructure projects, the production of coal will touch above 730 million tonnes by the end of the 12th plan (2012-2017) in India. With the projected local availability of 550 mt per year, India plans to mine an additional 240 million tonnes per annum (mtpa) of coal from 26 new fields in the next five-year plan. The current situation demands introduction of coal conversion technologies through indirect approach of coal gasification route. At present, many advanced nations worldwide have adopted the coal conversion process for production of synthesis gas for a variety of applications

including ammonia and methanol manufacture which is welcomed as commercially economic proposition.

With the arrival of methanol and syngas driven technologies for wide spectrum of chemical and petrochemical building blocks namely ethylene, propylene acetic acid, acetic anhydride, vinyl acetate, ethylene glycol, etc. there exists an immense potential in our country to explore and create facilities in this direction. If we monitor closely the status of the progress made within our country, the petrochemical industries based on petroleum, C_3 and its fractions of natural gas are only found in the western region due to its proximity to oil and gas fields. However, the eastern sector is more or less neglected with the only hydrocarbon based chemical industry at Haldia Petrochemical complex which produces ethylene, propylene, and other products.

Even the existing small scale chemical industries in the region are limited to coal carbonisation processes that are needed for steel plants. On the other side, the eastern part of the country enjoys a good reserve of coal, and the only sensible approach now is to explore this giant reserve of coal for the growth of many chemical industries to bring about a balance in all regions.

Coal Reserves in World and India

The world coal reserves and the percentage share of the countries involved are shown in Fig. 1. India contributes 7% of the total coal reserve in the world.

The year-wise coal reserves have been indicated in Table-1 which sums up to 298.914 x 10^3 million tonnes as per the latest estimation.

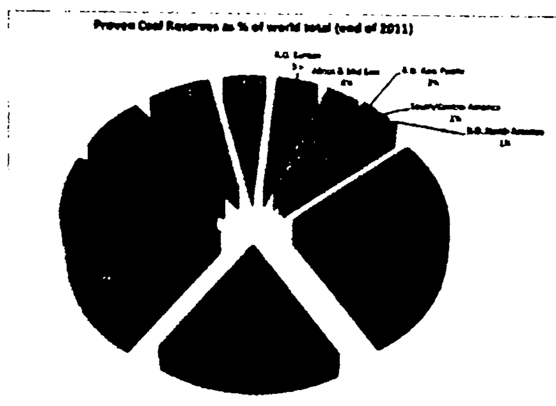


Fig. 1: World coal reserve and percentage contribution of individual nations

As on	Proved	Indicated	Inferred	Total (BT)
1.4.2007	99.060	120.177	38.144	257.381
1.4.2008	101.829	124.216	38.490	264.535
1.4.2009	105.820	123.470	37.920	267.210
1.4.2010	100.700	130.654	36.358	276.810
1.4.2011	114.002	137.471	34.389	285.862
1.4.2012	118.145	142.169	33.183	293.497
1.4.2013	123.181	142.632	33.101	298.914

The coal production of India touched more than 600 million tonnes compared to the consumption figure of around 700 million tonnes in 2011. This has been shown in Fig. 2.

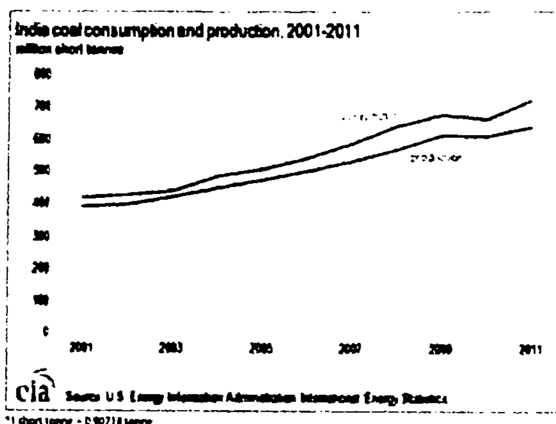


Fig. 2. Consumption vs. production of coal in India

Coal Reserves in Odisha

Odisha receives a great attention these days which is the threshold of industrialisation and a lot of significant progress is occurring in the creation of infrastructure facilities. This is the right time to share that attention with the utilisation of coal reserves by opening up of new chemical industries. It is beyond any doubt that a crucial quantity of non-coking coal reserves is sitting idle with a hope to get tapped for industrial utilisation. The status of the coal reserves in Odisha and its surrounding states have been illustrated in Fig. 3.

The main coalfields of Odisha are situated in Talcher and IB Valley with estimated recoverable reserves of

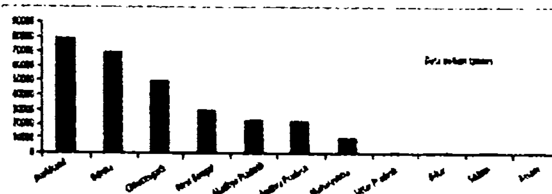


Fig. 3: Coal reserves in Odisha compared to other states

38.65 x 10^3 million tonnes and 22.3 x 10^3 million tonnes of coal respectively. The sum total yields about 70 x 10^3 million tonnes of coal from Odisha alone. These coalfields at present produce around 59.74 million tonnes at Talcher and around 44 million tonnes at IB Valley respectively which are utilised in power, fertiliser, cement, railways, and various other industries. The potential for the development of these collieries is already very high and it is estimated that by 2020, the Talcher coalfield will be able to produce over 100 million tonnes of coal and IB Valley about 80 million tonnes of coal per year.

The overall general analyses of coal from these fields are:

Coal	Moisture	Volatile Matter	Fixed Carbon	Calorific value Kcal/Kg
Takher	2.1	38.8	42.2	7830-7940
IB Valley	4.0	26.0	55.0	7400-7800

Coal	Carbon	Hydrogen	Sulfur	Nitrogen	Oxygen
Talcher	74.8	5.3	1.0	1.6	17.3
IB Valley	84.8	5.2	0.95	0.75	10.63

Source: Centre of Energy Studies, Delhi

Coal Conversion Chemicals and Process

The varying nature of conversion processes plays a key role to manufacture different varieties of chemicals. A complete list of the chemicals that can be manufactured is depicted in Fig. 4.

The synthesis gas preparation from coal involves basically coal gasification, gas conditioning, purification and by-product (if any) recovery and effluent treatment. The prominent and proven coal gasification processes are:

1. Lurgi fixed bed coal gasification
2. KT entrained bed gasification
3. Winkler fluidised bed gasification
4. Texaco coal slurry gasification.

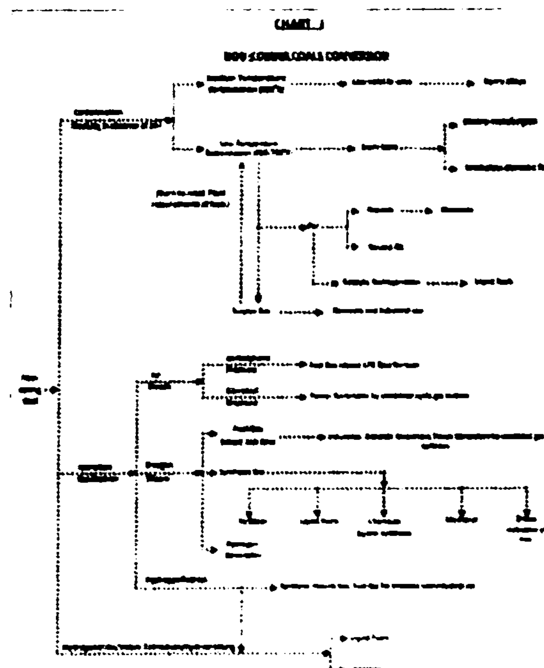
Amongst the available new generation technologies, Texaco pressure gasification technology is commercially proven which generates synthesis gas at relatively higher pressure without any formation of by-products. In the Texaco process, the feedstock is ground in a coal mill for coal water slurry preparation which is then charged to Texaco gasifiers with oxygen. The gasifiers operate at high pressures of 40 ata and above. The raw gas is cleaned and a mixture of dirt-free dominated by Hydrogen and Carbon monoxide is obtained. The raw gas is then purified by desulphurisation and decarburisation adopting rectisol wash. In case of ammonia production. high temperature shift (HTS) conversion unit, upstream of rectisol wash unit and liquid nitrogen as final stage of purification are followed. However, H_2 and N_2 ratio fixation is necessary.

CO + H_2 gas (Synthesis gas) is a versatile mixture which forms the core for the products that can be made from it. Fig. 5 highlights about various products that can be derived from synthesis gas.

Although presently, coal based technologies for production of synthesis gas are limited to mostly manufacture ammonia and FT (Fischer- Tropsch) synthesis products, the most exciting prospect lies in the production of methanol, oxo synthesis gas, CO, and H_2 following coal gasification routes.

Texaco coal gasification process is suitable for producing synthesis gas to facilitate oxo alcohol production, an important material in plasticiser, synthetic detergent, paints, and solvents.

High purity carbon monoxide for carbonylation can be manufactured from coal through gasification and purification which apart from being used for manufacture of acetic acid and its derivatives in conjunction with



methanol can be a source of raw material for phosgene, the feedstock for the manufacture of polyurethane and polycarbonates, many pharmaceuticals, and other expensive chemicals.

Methanol has now begun to show prominence as a substitute to naphtha in all its application as a transport fuel (gasoline) and as a chemical and petrochemical building block. There have been serious efforts and daring moves seen in the developed western world to widen the usage of methanol, but the pace is relatively slow owing to continuous effort on improving the energy efficiencies for conventional raw materials and technologies. But, India should accelerate the development of methanol application technology as a future replacement for petroleum and its products which are meager in supply. Proper policy measures can make coal based methanol projects viable if not competitive with gas based plants.

Methanol has the immense potential to emerge as an important chemical for a restructured chemical industry in relation to its economic advantage. Coal to methanol conversion technology has already been standardised and the conceptual design is already available. Coal to Ammonia plants through gasification, purification and synthesis are already under operation in India including the one at Talcher.

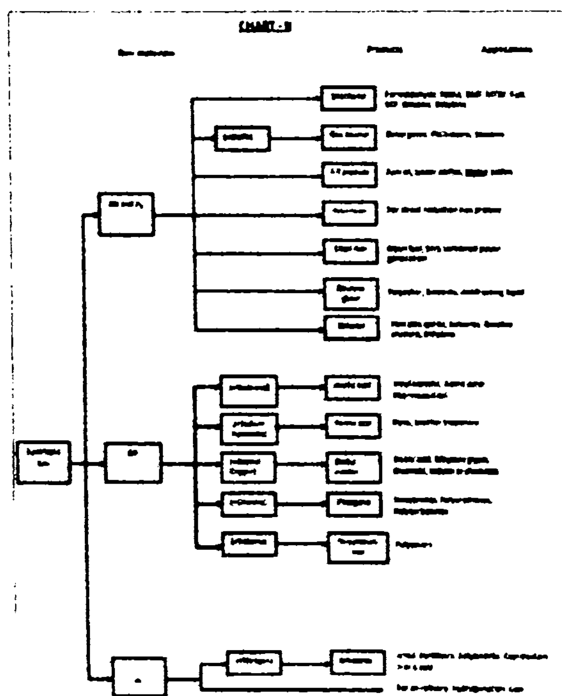


Fig. 5. Flow chart of all the possible products produced from Syngas

Revolutionary Concepts in Methanol-Oriented Technologies

Some of the revolutionary concepts for methanol-oriented technologies are indicated in Fig. 6 and are outlined briefly as follows.

a) Monsanto acetic acid process, Rhodium Iodide catalysts are used to promote reaction between methanol and syngas derived carbon monoxide to obtain acetic acid in single step reaction.

b) The Tennessee Eastman route esterifies methanol and acetic acid to methyl acetate and then carbonylated to acetic anhydride.

c) In Chevron process, methanol is converted to formaldehyde which reacts with CO and steam to form glycolic acid followed by esterification with methanol and reduction to glycol.

d) In Halcon process, methyl acetate formed in esterification of methanol and acetic acid is treated with syngas to derive ethylidene diacetate and it is subsequently cracked to acetic acid and vinyl acetate.

e) Mobil/Ruhr Chemie/BASF's development is directed toward production of ethylene/propylene based on zsm-5 zeolite catalyst.

f) Shell/Ruhr Chemie and BP' development is for homologation of methanol to ethanol which when

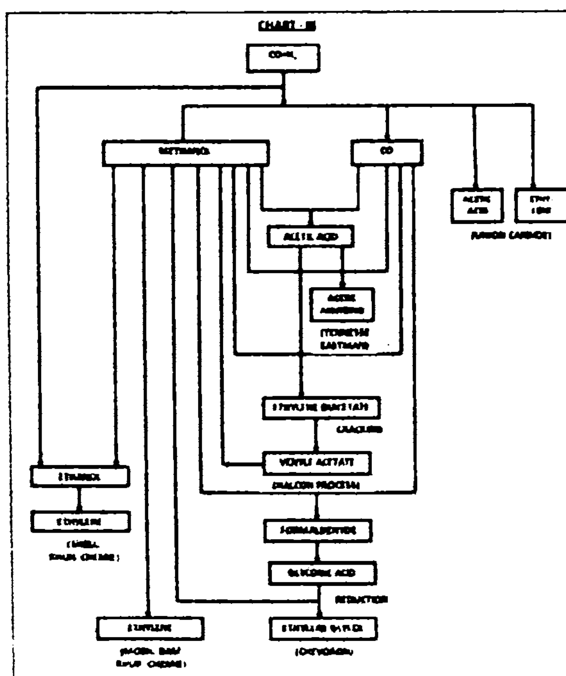


Fig. 6 Flow chart of possible methanol-oriented technologies

follows the conventional and established dehydration route can produce ethylene.

g) Union carbide is reported to be working on direct synthesis of syngas for acetic acid and ethylene making.

Economics of Coal Based Chemical Plants

In spite of coal being an indigenous raw material available in abundance in large part of the country and proven technologies ready for its conversion to high value products, the development of coal based chemical industry is still in its embryonic state and limited to two fertiliser plants at Talcher and Ramagundam in the country.

Though there was a lot of promise exhibited in the late sixties and seventies for the growth and development of coal based fertiliser and chemical industry, the discoveries of oil and gas fields in late seventies have dampened the progress. However, in changed scenario of scarcity and price hike of petroleum crude oil and its derivatives, coal based energy policy can gain ground as a step of self-reliance.

The main deterrents in the growth of coal based industry is the high capital related cost owing to capital intensive nature for its processing technology in spite of relatively low unit cost of energy. The upgrading of coal to high value products is associated with increasing order of loss of thermal efficiency. To secure the scale of economy, a coalplex requires a dedicated mine. It is also desirable from the point of view of close adherence to coal characteristics assumed for the design of gasifier operation. This is yet another advantage in locating the industry near pithead and avoiding movement of large volume of coal which otherwise entails high transportation cost besides putting considerable strain on the existing infrastructure of transport sector.

Based on the data available towards the end of 20th century, the production economics (qualitative only) for manufacture of methanol and ammonia from coal and natural gas have been calculated and presented in Tables 3 and 4 respectively. Further, the effect of raw materials prices on the sale price of methanol and ammonia has been presented in Tables 5 and 6 and illustrated in Figs. 8 and 9 respectively. That was the picture available to us at the end of 20th century which may have undergone severe changes with the development of technologies such as SASOL process in South Africa, LURGI process of Germany, etc.

If the price proportion of the previous century is taken into picture, the economy calculated on the current price will provide a better insight as per the example, the current sale price of coal and methanol produced from it are Rs. 161/Te and Rs. 34000/Te respectively. And, the sale price of natural gas and methanol produced from it are Rs. 4500/1000 Nm^3 and Rs. 9500/Te approx. respectively. So, the sale price difference between both the production routes of methanol is like Rs. 24000/Te which is very steep when compared to only Rs.1000/Te in late 20's. This clearly explains the price rise in raw materials in all these years that influence the sale price of methanol. The current variation in the methanol price in India and other countries has been shown in Fig. 7.

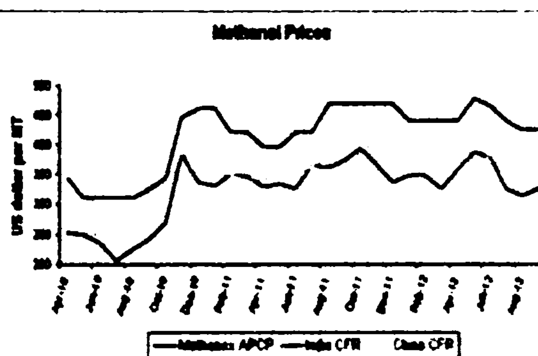


Fig. 7 Current price trend of methanol

	Feedstock	Coal	Natural Gas
1	Capital TPD	1500	1500
2	Capital Outlay (Rs. lakhs)	38500	2200
2.1	Battery limit plant cost	27200	8600
2.2	Offsite and Utility Plant	20300	6800
2.3	Other Fund Requirement Total Capital	86000	37400
3.	Operational Cost (Rs./Re)		
3.1	Variable Cost	571	2597
3.2	Fixed Cost	2663	1123
3.3	Contingency	73	150
4	Unit cost of production	3307	3870
5	Return on investment @ 15%	12600	1122
6	Ex-factory price including Return on Investment	5907	4992

Assumption

1. Gr E Non-coking coal with Ash 30%, moisture 7.5% and UHV-3725 Kcals/Kg. has been considered.
2. Location: Pithead for coal base and along gas pipeline for gas base.

	Feedstock	Coal	Natural Gas
1	Capital TPD	1350	1350
2	Capital Outlay (Rs. lakhs)		
2.1	Battery limit plant cost	34500	19600
2.2	Offsite and Utility Plant	20400	6800
2.3	Other Fund Requirement Total Capital	24700	12900
3.	Operational Cost (Rs./Re.)	79600	39300
3.1	Variable Cost	533	2507
3.2	Fixed Cost	2420	1176
3.3	Contingency	34	16
4	Unit cost of production	2987	3699
5	Return on investment @ 15%	2680	1323
6	Ex-factory price including Return on investment	5667	5022

		Gas base		Coal base	
		Natural Gas Rs./1000 Nm^3	Methanol Price Rs./te	Coal Price Rs./te	Methanol Price Rs./te
1	Base Case	2570	4992	161	5907
2	+10%	2827	5252	177	5954
3	+20%	3084	5509	193	6002
4	+30%	3341	5766	209	6049
5	+40%	3598	6023	225	6096
6	+45%	3726	6151	233	6120
7	+ 50%	3855	6286	242	6146

		Gas base		Coal base	
		Natural Gas Rs./1000 Nm^3	Ammonia Price Rs./te	Coal Price Rs./te	Ammonia Price Rs./te
1	Base Case	2570	5022	161	5667
2	+10%	2827	5272	177	5718
3	+20%	3084	5522	193	5769
4	+30%	3341	5772	209	5821
5	+40%	3598	6022	225	5872
6	+50%	3855	6272	242	5926

3. Raw Material Cost: Coal Rs.161/te, Natural gas Rs. 2570/- per 1000 Nm^3.

4. Process: Texaco Slurry Coal gasification & HT reformation.

5. If customs duty and sales tax on hardware is waived off in case of the ex-factory price, the sale price of methanol will reduce to Rs. 5400/te.

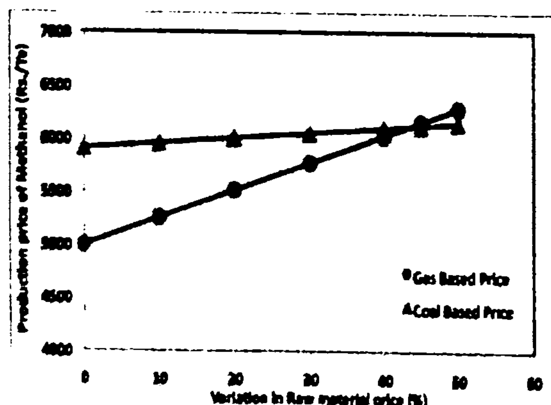


Fig 8. Effect of raw material prices on sale price of methanol

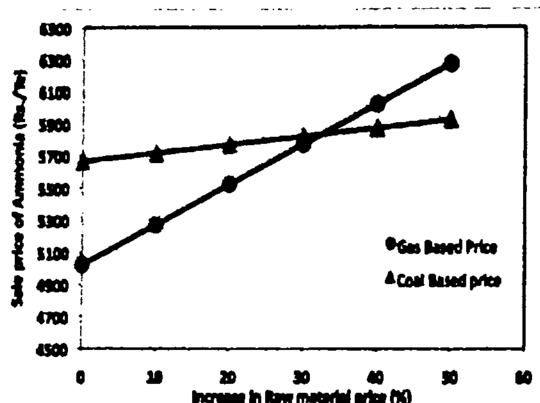


Fig 9. Effect of raw material prices on sale price of ammonia

Justification of Coal Based Chemical Industry in Eastern India

Establishment of coalplex is justifiable on following counts:

i. In the eastern region, natural gas is not available except some find in Tripura and Krishna Godavari basin of Andhra Pradesh.

ii. Utilisation pattern of natural gas and naphtha should be restricted to optimal usage. Various forms of petroleum derived energy sources should be limited and reserved for traditional use which cannot be met or substituted by any other forms of energy.

iii. Present evaluation of energy resources indicates that the natural gas and naphtha availability are not sufficient to plan future augmentation of capacities for fertiliser and petrochemical based industries.

iv. Conversion energy efficiency for methanol and ammonia is around 55% and in such cases, utilisation of high cost natural gas/naphtha is not desirable.

v. The prices of both coal and natural gas are likely to rise in future. The rise in coal price can be gradual keeping in view of its impact in other sectors of economy. But in case of natural gas and other petroleum products, the fluctuations would be more pronounced and are influenced by international trade. Gas price is generally determined on opportunity cost basis for replacement of alternative feedstock and sometimes also on energy equivalent basis on cost of naphtha. Hence, in any unprecedented oil as witnessed on earlier occasion and steep price hike situation, unit cost of energy in petroleum originated hydrocarbon can be exorbitantly high in comparison to coal. In such circumstances, production economics of coal based chemicals intermediates is expected to be much favourable and attractive. Tables 5 and 6 give an idea of the effect of uniform escalation of price of coal and natural gas on methanol/ammonia. It works out that at 43% escalation of both natural gas and coal prices over the base price assumed, the sale price of methanol becomes identical in both cases at Rs. 6100/Te. The corresponding coal price

would be Rs. 230/Te and natural gas Rs. 3675/1000 Nm^3. As a long-term national strategy, coal based chemical industries have considerable potential for realisation of socio-economic benefits. The industry being a labour intensive one to an extent may solve the unemployment problem both through direct and indirect employment procedures.

vi. Precedents are there in our country where strategic decisions have been taken for development of core sector industries not only purely from economic angle but also national interest. As on illustration, power generation through atomic energy resources is associated with high incidence of capital and generation cost involving additional inherent risk factor. Notwithstanding, large sums of money are being spent to expand atomic power generation capacity.

Conclusions

In view of the fast depletion of oil and natural gas, the economy is badly affected which is further worsened by the absence of any significant discoveries to utilise the present resources. Complementing to this scene, the possibility of exploiting the fossil fuel energy in the form of coal also looks gloomy due to the absence of innovative technologies to produce value-added chemicals. Besides, there are also some already proven commercial technologies which have been continuing since long, and they are becoming a hindrance for the new innovations to prove success in the commercial level. Hence, the need of the hour may be focused to implement favourable fiscal policies and fuel policies to stimulate the growth of coal based chemical industries in the state of Odisha.

Looking at the prospective in terms of resource contents and fast growing infrastructure, Odisha can certainly take pioneering steps in welcoming a new era of industrialisation through the growth of coal based chemical industries. In attending this objective, both the state and the country can keep pace with the technological advancements taking place in western world countries that are industrially developed. So, Odisha should recognise this bold opportunity to initiate steps in the required direction and be geared up with the modern technology and expertise to serve an example to others in utilising the coal resource and developing the coal based chemical industries.

In the past, based on our non-coking coal reserves at Talcher, a fertiliser plant which was the only one of its kind for production of urea and ammonia was installed. After successful operation for two decades, in 2002, this plant was closed due to the absence of suitable grade of non-coking coal at Talcher. Recently, the Central Government has already announced the revival of Talcher Fertiliser Plant with the required gasification technology compatible to the grade of coal available at Talcher. This will certainly open up many other possibilities due to the fact that the gasification plant will be the base for not only ammonia and urea production, but also provide other possibilities for the manufacture of various coal based chemicals.

Acknowledgement

The authors wish to acknowledge Prof. B. K. Mishra, Director, Institute of Minerals and Materials Technology for his permission to publish this paper.

• *Source: Iron and Steel Review, Vol. 57, No. 11, April 2014, pp 136-146.*

CHAPATER 9

Legendary Biju Patnaik & His Vision for Industrialization of Odisha

My Association with Sri Biju Patnaik
Former Chief Minister of Odisha for Industrialization of the State

Dr. Ing. H P Mishra
Ex-Chairman. IPICOL. Odisha

In this competitive world, technological knowledge and innovation are considered as prime input. Biju Babu's dream for development of Odisha was based on these two most important aspects. My association with him dates back to the year 1955 when I returned back from West Germany after completing my Doctorate in Metallurgical Engineering from T.H Aachen. This was possible only because of my God Father Dr. Haribandhu Mohanty who was Industrial Adviser to the Government of Odisha. He helped me throughout my educational career. I was appointed in Germany to join Rourkela Steel Plant by Hindustan Steel Ltd. After returning from Germany, I was probably the one of the first Technical Officers entrusted with the responsibilities to look after the Chemical Units of the Steel Plant. After working for some time for Coke Oven Plant, I was asked to conceive a project based on the Coke Oven Gas from the Steel Plant. Steel units were not developed and therefore we thought of putting a Fertiliser Plant based on the Coke Oven Gas. I was Officer- in - Charge of the Plant and implemented it primarily with German Collaboration. On the day of commissioning of the plant, Biju Babu as the Chief Minister of our state came along with German Dignitaries. After the commissioning of the plant, he asked our General Manager to find out a suitable person who can help him to put a Fertiliser Plant at Talcher based on Talcher Coal. Our General Manager recommended my name and I joined as Chief Executive Officer of Industrial Development Corporation of Orissa Ltd (IDCOL) in lien from Government of India. After that Biju Babu and I came in close contact with each other. I was primarily engaged for promotion of Talcher Fertiliser Plant for four years before shifting to Bokaro Steel Plant of the Government of India.

After staying in Bokaro for nearly 4 years, Govt. of Odisha persuaded me to join the State Govt. as Managing Director, IDCOL. Thereafter, I remained in the State Govt. till 1984. During my stay for nearly 15 year in Odisha, I had very intimate connection with Biju Babu whether he is in power or not. I was a constant visitor of Naveen Nivas. He was a dreamer par excellence as regards development of Odisha was concerned and was incapable to think in a small

way. I am noting below some of my experiences during my tenure in the State Govt. Corporation.

(1) When I joined as Chief Executive in Industrial Development Corporation, I had the occasion to go with him to Paradeep. Paradeep Port was initiated by him. He was thinking to join the port with the mining area of Tomka. Daitari. There was a problem of making a road from the Port to Mining Area mainly for export purpose. Chief Engineer of our State Govt. along with other concerned officers was in the meeting. He said while scanning the Odisha Map. there is no problem. He drew a straight line on the map from Paradeep to Daitari and said that the Express High Way must be designed accordingly. In Paradeep Port he was thinking of putting up a Steel Plant and I along with my team members were given the task in the year 1977 when he was the Union Steel & Mines Minister. We were almost to sign a contract with M/s Davy McKee. Suddenly the Central Ministry was changed and the New Government asked us to find out a suitable place within a radius of 100 km from Paradeep for putting up the Steel Plant. The contract set up for the purpose selected Kalinga Nagar as the possible site. I happened to be the Secretary of this Committee. Neelachal Ispat Nigam was promoted by IPICOL. Subsequently. IPICOL promoted the MESCO, VISA, Tata Steel Plant and many other units were located at Kalinga Nagar. At Paradeep, IPICOL promoted the Paradeep Phosphate Ltd. and IFCO Fertiliser Plant and Paradeep Refinery Unit. M/s POSCO from South Korea decided to locate a Mega Steel Plant at Paradeep but some petty political interest has not made it possible so far to ground it.

(2) When IPICOL was formed, National Aluminium Company Ltd. was one of the first projects to be promoted. In this effort of mine, Biju Babu helped us a lot. He was the Union Minister of Steel & Mines of Government of India in 1977. IPICOL took a pioneering role in discovering Pattangi and Panchapattamali as the source of the Bauxite Mineral and conducted lots of tests in our National Laboratories. M/s MECON, Ranchi prepared the Project Report for 80, 000 TPA Alumina and 50. 000 TPA Aluminium production facilities. At that time, I was going to Delhi almost every fortnight to contact Biju Babu for the adoption of this project by Govt. of India. I had the good fortune to be a guest at lunch in his house at 3 Aurungzeb Road in New Delhi. Biju Babu wanted to increase the capacity of Alumina Plant to 2 lakh TPA and Aluminium Plant to 1 Lakh TPA. But the resource constraint especially

for the Power Plant at Angul did not make it possible. The plant is now one of the Navratna Company of the Govt. of India Public Sector Project.

(3) Similarly the promotion of Indian Rare Earth Project was possible at Gopalpur by IPICOL with the help of Biju Babu. Biju Babu introduced me to Dr H.N. Sethna of Atomic Energy Commission. My friend Muralidhar, Managing Director of IRE included it as one of the Prime Projects of Atomic Energy Department of govt. of India.

In my journey for the industrialization of my state, Biju Babu for me was the prime motivator. Kalinga Iron Work expansion, Ferro Chrome Project, Sewa Paper Mill at Jeypore, Odisha; Synthetic and IPIBEL Refractory at Dhenkanal. Sponge Iron Units at Keonjhar; Ferroalloy and Tyre Project at Balasore were promoted during my tenure in IPICOL due to the assistance provided to IPICOL. All this happened during the tenure of Biju Babu is Chief Minister of Odisha and Cabinet Minister in Govt. of India. My Journey & Dream of Industrial Renaissance of Odisha were realised due to the blessings, goodwill and strong will power of my Mentor and Hero Biju Babu.

My personal connection with Biju Babu is like an elder brother to younger one. I cannot forget one incident in my life in 1979. Biju Babu as Steel Minister of the Govt. of India took a meeting regarding the industrial program in our state in 3rd floor Conference Room of our Secretariat. Shri Nilamani Routray was our Chief Minister. He expressed his anger to each one of us present in the meeting. When my turn came, he asked me about the delay in grounding the projects like Ferro Vanadium & Ferro Nickel etc. I replied that these Project Works including Project Reports have been completed by IPICOL but my friend Shri Wahid Khan, Chairman, SAIL wanted to get it implemented in Central Sector under SAIL. He went through the correspondence and affectionately said you deserve a lunch with me. I was a constant visitor of Naveen Nivas and had lunch with him.

In this advance age of 91, I still remember Biju Babu as one of the Prime Mover of Industrialization of our State. Biju Babu and myself jointly planned to develop Industrial Corridor connecting Paradeep, Kalinga Nagar, Keonjhar, Rourkela, Jharsuguda, Angul, Dhenkanal, Cuttack & Paradeep with Industrial Park adjacent to each Mega Steel Project to convert the Basic Metal to Technological Products with Value Addition & Employment Generation. We

chalked out the basic infrastructure for land, power, water etc. He was motivating me to help Odia Techno Entrepreneurs like Dr. Bansidhar Panda to be created and IPICOL to provide Venture Capital which will help them for equity participation. Although some progress has been made in this direction, it is time that Government must take conscientious decisions to implement projects like Ferro -Nickel, Ferro -Vanadium, and Alloy Steel like Aluminium, Silicon and Lithium Alloy. Real industrialization of our state can be measured how much of Basic Metal produced in our State is converted to Technological Products for National and International Market in our State.

In conclusion I would like to make the following observation:-

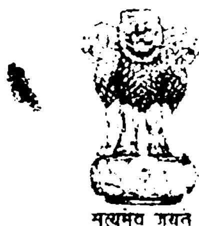
Biju Babu's association with me could not continue in the last phase of his Chief Ministership primarily because of his health condition and the technical team which he was able to build initially could not be retained due to various reasons. He was a man of bold personality with deep human touch. He was not very much involved in Seminars or Lectures. He believes in Practical Action in the Ground Level and the Developmental Projects whether in Industry, Agriculture, Irrigation etc. should be completed in time and must reach to the poorest of poor people to mitigate their suffering under peculiar circumstances. When he was not in power, against his advice, I was asked to retire in 1984 as I reached superannuation age. But at this phase of my life, I strongly feel that some of the Prime Mineral based Projects like Ferro-Nickel, Ferro-Vanadium are required to be grounded soon to convert our Waste to Wealth for which personally I have spent lot of my Professional Time with his motivation.

In the evening hours of my life, I pray to the almighty to bless our state with such leaders in Political and Technological fields who can ground our dream of Industrialization and create Steel Corridor in near future to provide value for our God gifted Natural Resources. This will be best tribute to Sri Biju Patnaik, the Pioneer for the Development of our State. For him the Development of our State was of Prime Importance and to my knowledge he was never fond of so called Political Power or Power to Personal Future.

CHAPATER 10

Appreciation letters received from various Distingusihed Dignitaries of the Country

हरीश रावत
ہریش راوت
Harish Rawat



राज्य मंत्री
कृषि, खाद्य प्रसंस्करण उद्योग एंव संसदीय कार्य
भारत सरकार
وزیر مملکت
ایگریکلچر، فوڈ پروسیسنگ انڈسٹریز و پارلیمانی امور
بھارت سرکار
MINISTER OF STATE
AGRICULTURE, FOOD PROCESSING INDUSTRIES
& PARLIAMENTARY AFFAIRS
GOVERNMENT OF INDIA

3 August 2012

Dear Dr. Mishra Ji,

Please accept my sincere thanks for the two books you presented me at Bhubaneswar on 31 July 2012. The books are indeed informative and will be immensely useful for planners, policy makers, academics and entrepreneurs.

I highly appreciate your painstaking efforts and wish you good health and happiness.

Yours sincerely,

(Harish Rawat)

Dr. Haraprasanna Mishra
222/1 Shashtri Nagar
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Bhubaneswar
751001
Odisha

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B.E. (Hons), ME (Soil), D Engg. (Hon)
FIE, FISTD, FAIMA, FIIM, MICWA, MIPM, MIChE, MIME, MICA
Dean cum Director General & Vice Chairman
Former Director, Vedanta Resources Plc, London
President & Chief Executive Officer, INDAL
President, Aditya Aluminium, HINDALCO
Chairman-cum-Managing Director, NALCO

Bharatiya Vidya Bhavan, Bhubaneswar Kendra
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Web : www.bvbbhubaneswar.org

Date: 31.10.2012

Dear Dr. Misra

Your book "Technical Excellence of Odisha Industrialization" is in hand. I am thankful to you for your generosity and thoughtful gesture.

I have glanced through the Book. It is an excellent effort by you in documenting your experience and knowledge with the Industry in Odisha over a long period of your keen involvement. Articles in the book covers a wide variety of minerals and subjects ranging from efficient processing of minerals to utilization of waste, recovery of strategic minerals and technological up gradation.

This is a very useful guide to the Industry and researchers. I congratulate you for your efforts and for providing continuous guidance.

I wish you many more active years so that we could continue to be benefited with your advise.

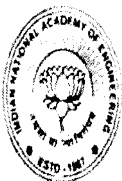
With Best regards,

Yours Sincerely

(Dr. S.K.Tamotia)

Dr. H.P.Mishra, FIE
222/1, Shastri Nagar
Unit – IV
Bhubaneswar - 751001

CENTRE FOR COMMUNICATION AND MANAGEMENT, BHUBANESWAR



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DR. BALDEV RAJ, FTWAS, FNAE, FNA, FASc, FNASc
President

President, International Institute of Welding
Hon. Member, International Comittee on NDT
Hon. Member, Indian Institute of Metals
Member, German Academy of Sciences, Academia NDT International

President, PSG Institutions
New Administrative Block, Peelamadu
Coimbatore-641 004 (Tamil Nadu)
Tel : 0422-4344201
Email : baldev.dr@gmail.com
dr.baldev@psg.org.in

25th June, 2012

Dear Prof. H P Mishra,

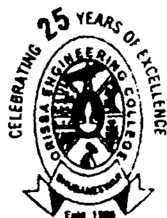
I thank you immensely for sending a copy of the book titled 'Technological Excellence of ODISHA Industrialisation'. I appreciate your remembering me and sending me the book.

I wish you and your family members the very best. I look forward to the opportunity of meeting you, at the earliest possibility.

Yours sincerely

Baldev Raj

To:
Prof. H P Mishra
222/1, Shastri Nagar, Unit-IV,
Bhubaneswar – 751 001,
Orissa.



ORISSA ENGINEERING COLLEGE

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Ref. OEC/P/667/2012 Date. 06/10/2012

LETTER OF APPRECIATION

I am happy to learn that **Dr. H.P. Mishra**, one of the eminent technocrats of Odisha could translate his powerful ideas, plans and execution of various projects on utilization of mineral and material resources in a single volume entitled **"Technological Excellence of Odisha Industrialization"**. This volume is a compilation of technical articles published and presented over the years various National and International fora. Dr. Mishra has conducted many pilot experiments in his humble and sincere journey through the Mineral and Materials World with a special reference to technological investigation of Odisha. An exhaustive literature together with experimental findings have been documented in this compendium. Hopefully, this volume shall cater to the needs of students, faculty, police makers, entrepreneurs and others working in the domain of technological and industrialization revolution of minerals and materials.

Orissa Engineering College, Bhubaneswar places on record its deep appreciation for the donation of a book entitled **"Technological Excellence of Odisha Industrialisation"** by **Dr. Haraprasanna Mishra**, F.I.E., Ex-Chairman, IPICOL, 222/11, Shastri Nagar, Unit-IV, Bhubaneswar-751001.

06 Oct 12

Principal
Orissa Engineering College
Bhubaneswar



SOCIETY OF GEOSCIENTISTS AND ALLIED TECHNOLOGISTS

(Registered under the Societies Registration Act, XXI of 1860)
Registration No. PR-388-175 of 1981-82

Dr. S.K. Sarangi
President

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IRC Village, Nayapalli,
Bhubaneswar – 751015,
Odisha, India
Mob:+91 9937023134
E-mail: drsks62@yahoo.in
geomin@satyam.net.in

Date: 28.08.2012

Dr. H.P. Mishra, F.I.E
222/1, Shastri Nagar
Bhubaneswar – 751 001

Dear Sir,

You are aware of the fact that SGAT has introduced a new membership as **"Fellow"** wherein a member having minimum 10 years of experience can become a "Fellow".

The Executive Council is pleased to elevate your membership to "Fellow" as a respect to your dedicated contribution to the growth of the Society.

You are requested to write FSGAT as a suffix to your name.

Thanking you

With regards

(Dr. S.K. Sarangi)



Ashwin Shroff
Chairman & Managing Director

EXCEL INDUSTRIES LIMITED
184-87, Swami Vivekanand Road,
Jogeshwari (W), Mumbai - 400 102.
Tel.: +91 22 2678 2944 ★ Fax : +91 22 2678 3732
E-mail : ashwin.shroff@excelind.com

26 July 2012

Dear Dr. Misraji

Greetings!

First of all, let me express my gratitude to you for sending the book "Vision on Industrialization for Odisha State" co-authored by you.

I enjoyed going through the book. You have made an in-depth study of the mineral resources especially prospects of Titanium and Iron ores based industry of the Odisha state, current and past industrial scenario of the state and need of the State Govt. to enact appropriate planning for its future growth.

Your thoughts on improving the infrastructure quality and need of proper planning have come out very well.

You have rightly stressed upon the need of human resources with adequate technological expertise to harness the vast mineral resources of the state as also need of proper planning and efforts in making professionals as entrepreneurs.

This master piece making a comprehensive coverage of Industry scenario will help the Govt. as well as Industrialists and entrepreneurs to bring Odisha on higher path of growth.

Besides the comprehensive and in depth coverage of the subject matter, the lucid style of writing will make the book interesting reading.

My heartiest compliments to you for penning this wonderful book.

Warm Regards

Ashwin Shroff

Ashwin Shroff

Dr. Eng. H P Misra
Ex-Chairman, IPICOL
222/1, Shastri Nagar
Unit-IV, Bhubaneshwar – 751001
Odisha
Cell : +91 9338555729



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K. K. MEHROTRA
Chairman-cum-Managing Director

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फैक्स / FAX : 0651-2482401, 2482194, 2482189
ई-मेल / E-MAIL :cmd@meconlimited.co.in
वेबसाइट / Website : http://www.meconlimited.co.in

July 19, 2012

Dear Dr. Misra,

Thank you very much for your letter of 13th instant. I greatly appreciate receiving a copy of book "Technological Excellence of Odisha Industrialization" authored by you. The book contains valuable and interesting information and I have sent the book to our Technical Information Centre for reference by our engineers.

Compilation of this nature will serve to immensely strengthen the knowledge-base and I am sure that this publication will serve as a source of vital information not only to industries, institutions and students but also to entrepreneurs planning to set up industries in Odisha. Your efforts put in for bringing out such a wealth of information are laudable and I compliment you for this.

With best regards,

Yours sincerely,

(Signature)

Dr. Eng. H.P. Misra,
222/1, Shastri Nagar,
Unit-IV,
Bhubaneswar 751 001

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FAX (+91-33) 2225-1422 & 2225-7101
E-Mail rmd@dasturco.com

13th August 2012
5-5389A

Dr. Eng. H.P. Mishra
222/1, Shastri Nagar
Unit-IV
Bhubaneswar 751 001

Dear Dr Mishra,

I am in receipt of your letter of 22nd June 2012 enclosing the book titled "Technological Excellence of Odisha Industrialization. I could not reply to your letter earlier as I was travelling most of June-July 2012.

I have briefly gone through the book and find it contains valuable information borne out of your long association with the industrial development and progress of Odisha. As desired by you, the book will be preserved in our Library, and I am sure this book will definitely be useful for our engineers.

With warm regards,

Yours sincerely,

R.M. Dastur

RMD:mvu



CSIR-NML

राष्ट्रीय धातुकर्म प्रयोगशाला
(वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद्)
जमशेदपुर - 831 007, भारत

National Metallurgical Laboratory
(Council of Scientific & Industrial Research)
Jamshedpur - 831 007, INDIA



डॉ. एस. श्रीकांत, एफ.एन.ए.ई., एफ.एन.ए.एस.सी.
निदेशक
Dr. S. Srikanth, FNAE, FNASc
Director

No.NML/D/7.20
July 13, 2012

Dear Dr. Misra,

Thank you very much for sending me the book "*Technological Excellence of ODISHA Industrialisation.*" At the outset, I wish to say that you put up a phenomenal effort to bring out this compilation. I will go through this book in leisure and let you know my comments on this book.

With warm personal regards,

Yours sincerely,

Ssrikanth

(S. Srikanth)

Dr. Eng. H.P. Misra
222/1, Shastri Nagar
Unit-IV
Bhubaneswar 751 001

दूरभाष/Phone : (0657) 2345202 / 2345028 (O), 2223864 (R), फैक्स/Fax (0657) 2345213
ई-मेल/e-mail : director@nmlindia.org / ssrikanth@nmlindia.org, वेबसाइट/Website : www.nmlindia.org
Working Days : Monday to Friday (09.15 am - 05.45 pm)



H M Nerurkar
Managing Director

January 5, 2012

Dear Dr Misra

I sincerely thank you for your New Year Greetings, which I heartily reciprocate.

With best wishes to you and your family.

Warm regards,

H M Nerurkar

Dr H P Misra
222/1 Shastri Nagar
Unit IV
Bhubaneswar

TATA STEEL LIMITED
Jamshedpur 831 001 India
Tel 91 657 2424602 2145625 Fax 91 657 2431818 e-mail hmnerurkar@tatasteel.com
Registered Office Bombay House 24 Homi Mody Street Mumbai 400 001



H M Nerurkar
Managing Director

January 5, 2012

Dear Dr Misra

I sincerely thank you for your New Year Greetings, which I heartily reciprocate.

With best wishes to you and your family.

Warm regards,

H M Nerurkar

Dr H P Misra
222/1 Shastri Nagar
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Bhubaneswar

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Jamshedpur 831 001 India
Tel 91 657 2424602 2145625 Fax 91 657 2431818 e-mail hmnerurkar@tatasteel.com
Registered Office Bombay House 24 Homi Mody Street Mumbai 400 001



Dr Amit Chatterjee
Advisor to the Managing Director

30 Oct 08

Dear Dr Misra.

In response to your letter of 27.10.08. I was happy to see that the Monograph edited by you and your colleagues on Nickel in Orissa. was released in the Golden Jubilee function of The Institute of Engineers (Orissa Chapter) where you were also felicitated.

You have always pursued the subject of nickel extraction from Sukinda COB with a lot of passion. but unfortunately. nothing has happened so far. Because of the very low nickel content. unless there is a technology breakthrough. it is unlikely that the COB by itself can ever be used for extracting nickel. Of course. it can form a blend with richer ores.

Congratulations nonetheless on the release of the Nickel Monograph.

Best wishes.

Yours sincerely.

AC 30.10.08
Amit Chatterjee

Dr HP Misra
222/1. Shastri Nagar
Unit-IV
Bhubaneswar – 751 001.

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Registered Office Bombay House 24 Homi Mody Street Mumbai 400 001



Dr. Ing. H P Misra, F.I.E.
222/1, Shastri nagar,
Unit –IV
Bhubaneswar 751 001

B Muthuraman
Vice Chairman

11 June, 2012

Dear Dr. Misra:

Many thanks for your letter of 22 May, 2012 enclosing your recent book, "Technological Excellence of Odisha Industrialisation" and the bio-data of your grandson, Sadananda Acharya.

I have glanced through your book. I will read it in details later over the weekend. I cannot think of a more appropriate person to talk about or write about the industrial history of Odisha. You have had a rich and varied experience in several areas involving metallurgy and engineering that your thoughts and words undoubtedly carry huge credibility.

Regarding your grandson, I will ask Tata Steel and TCS to examine his bio-data and take appropriate action.

It is always a pleasure to get a communication from you and interact with you. Next time I am in Bhubaneswar, we will try to meet each other.

With warm regards,

B Muthuraman

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